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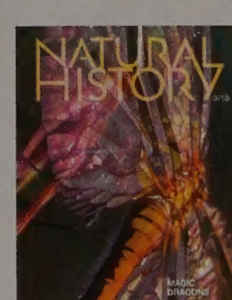
MAY 2015 VOLUME 123 NUMBER 4

FEATURES

DEPARTMENTS



ON THE COVER:
The wings of a black meadowhawk have a complex rigid surface that is maintained by a network of veins. Reflected sunlight yields subtle colors on this recently emerged dragonfly, whose wings are not yet transparent.
Photograph by Pieter van Dokkum

THE NATURAL MOMENT

SPEARHEAD

Photograph by Mac Stone

◄ See preceding two pages

Anhingas go by many names: darter, devil bird, water turkey, and snakebird. The latter moniker comes from the birds' tendency to swim with their head and serpentine neck held above the water, looking a bit like a snake primed to strike. Such a strike, for anhingas, however, usually happens fully submerged underwater. Courtesy of specially hinged cervical vertebrae, with underside protrusions called keels, the birds can snap their heads at tremendous speed, spearing small fish with their sharp beaks.

American anhingas (*Anhinga anhinga*) live in coastal areas in the southeastern United States; in Mexico, Central America, and parts of the Caribbean; and east of the Andes in South America. Photographer Mac Stone saw the anhinga pictured on the previous two pages—with an alligator sliding by in the background—on Anhinga Trail in Everglades National Park. The trail is about fifty miles southwest of Miami, close to Homestead, Florida. Surrounded by sawgrass marsh, the anhinga spread its wings, in a post-bathing ritual, to dry off. "The bird doesn't produce natural oils, like ducks do, to stay buoyant, so it can submerge easily and stay underwater longer to hunt," says Stone. A lack of preening oils, or a requisite functional uropygial gland, means the birds get weighed down by waterlogged feathers until they can dry their spread wings, bent at the "elbows."

One name an anhinga should not be called is cormorant, a pejorative these days in certain fishing communities. Although there are many similarities between anhingas and double-crested cormorants, and the birds even associate in breeding colonies, the U.S. population of double-crested cormorants has spiked dramatically in the last two decades, whereas anhingas remain protected under the Migratory Bird Treaty Act of 1918. The culling of cormorants to protect other species, such as salmon in the Pacific Northwest, can create quite a stir [*see "To Kill a Cormorant," by Richard J. King, March 2009*].

One thing is certain: you won't likely mistake the sound of the two birds' calls. Anhingas make clicking noises akin to a sewing machine, and utter the occasional guttural rattle. Double-crested cormorants grunt like pigs.

Photographer **Mac Stone**, from Gainesville, Florida, focuses his camera on American swamps in the hope of increasing public awareness about wetland species. For these photographs and others included in his recent book, *Everglades: America's Wetland* (University Press of Florida, 2014), Stone spent five years living and working in the Everglades watershed. More of his work can be seen at www.evergladesbook.com and www.macstonephoto.com.

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Additives Add Nothing

COURTESY OF MSU

MSU researchers show that several additives that claim to break down plastics simply don't work.

The "nature.net" column in March described the current state of degradable, biodegradable, and compostable plastics. As reported, the Center for Sustainable Polymers at the University of Minnesota is hard at research to make plastics truly green while retaining all their advantages over alternative materials. A team of researchers at Michigan State University (MSU), however, has completed a three-year study that shows several additives claimed to break down the polymers in plastic bags and soda bottles simply don't work in such common disposal sites as landfills and composts.

The study focused on five additives and three categories of biodegradation, which cover the majority of methods available on the market today. The team studied biodegradation with oxygen, as in composts; without oxygen, as in landfills; and by simple burial, as in your own backyard. "There was no difference between the plastics mixed with the additives we tested and the ones without," said Rafael Auras, coauthor of the study and professor at MSU's School of Packaging. "The claim is that, with the additives, the plastics will break down to a level in which microorganisms can use the decomposed material as food. That simply did not happen."

Susan Selke, the acting director of MSU's School of Packaging and the other author of the study, points out that it was the package-user companies that funded the study because "they wanted to know if the additives that are being marketed to them work. They wanted scientific proof to evaluate the products and disposal approaches that are available to them to break down plastic." She adds, "Making improper or unsubstantiated claims can produce consumer backlash, fill the environment with unwanted polymer debris and expose companies to legal penalties." A paper on the study was published in the February 27, 2015, issue of *Environmental Science & Technology* (pubs.acs.org/doi/abs/10.1021/es504258u). A nontechnical account of the study is provided at msutoday.msu.edu/news/2015/additives-to-biodegrade-plastics-dont-work.

WORD EXCHANGE

Just One Word: Plastics

You report ["nature.net," 3/15] that in 1999 Captain Charles Moore discovered a sea of plastic the size of the state of Texas collecting in the North Pacific gyre, and that when he returned in 2009 that collection of plastic had seen an enormous increase. Perhaps—while we hold our breaths for the development of degradable plastics—this and other natural oceanic collection points for floating plastic should be harvested for commercial mining and recycling.

Harold M. Craig
Winsted, Connecticut

Damage Control

I was pleased to read Bernd Heinrich's "Chickadees in Winter" [3/15] and only wish to suggest that the article subtly perpetuates a bias I've struggled against for all of my fifty years studying moths. Heinrich refers to the "feeding damage" caterpillars leave on leaves. But why speak of damage? Caterpillars do what all other animals, including chickadees, do—they eat. When a chickadee eats a caterpillar, it kills a baby butterfly or moth. Yet we do not accuse the chickadee of being a killer, or of causing damage. Be happy the caterpillars are there to supply food for birds and many other organisms.

Eric H. Metzler
Alamogordo, New Mexico

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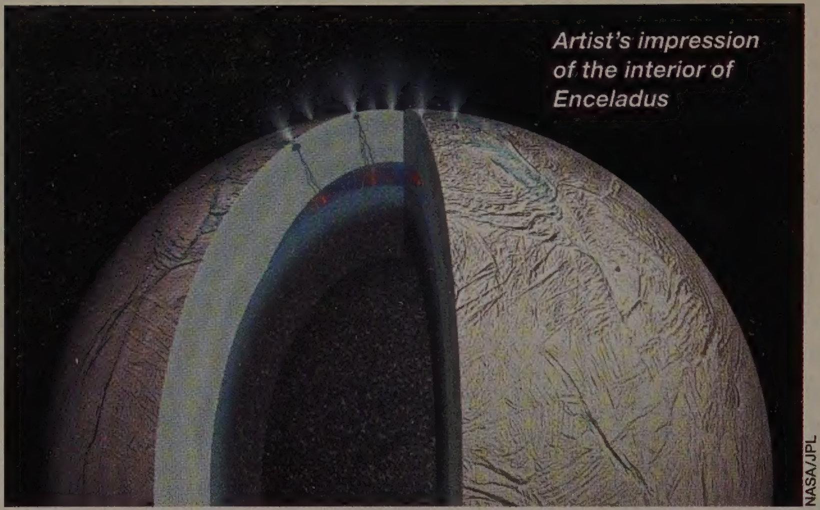
SAMPLINGS

Giving Vent



Hydrothermal vents—ocean floor fissures gushing mineral-laden, superheated water—are among the harshest environments on Earth. Yet they support rich ecosystems of microorganisms that can survive the intense heat and surrounding cold as well as the high pressure and lack of light found in those environments. Scientists have wondered whether similar vents could provide pockets of habitability on other worlds. Enceladus, a moon of Saturn, could be such a place.

Enceladus's thick, icy crust is laid bare to space, but it has a subsurface ocean of liquid water, as well as internal heat thought to be produced by gravitational tidal interaction with its host, Saturn, and with a neighboring moon. The ocean's heated liquid was detected in 2005 when NASA's Cassini probe spotted geysers shooting from the moon's south polar region. Grainy particles like those coming from these geysers form most of Saturn's broad E ring, in which the moon is embedded.

In a new study, Cassini's instruments revealed grains coming from the geysers to be almost pure silica, a common mineral on Earth. Furthermore, the origin of the grains, which had a radius of up to six to nine nanometers (billionths of a meter), looks to be vents hidden in Enceladus's watery interior.

To find out how the grains came into being, fourteen scientists led by Hsiang-Wen Hsu of the University of Colorado Boulder ran experiments simulating the interactions between water and rock likely occurring under Enceladus's skin. A water solution containing ammonia, carbon dioxide, and sodium salt was used to mimic the suspected makeup of the moon's ocean. For the rocks, Hsu and colleagues opted for minerals such as pyroxene and olivine. The concoction was cooked under high pressure for months.

Silica particles of the right nanoscale dimensions turned up in the watery solution once it cooled. Such cooling would be expected to happen in Enceladus's ocean, under specific conditions, some distance away from rock faces. Hsu and colleagues seemed to have figured out the right recipe for creating the silica particles: the temperatures at Enceladus's ocean bottom must be at least 190 degrees Fahrenheit, the pH rather basic, and the water not particularly salty.

The findings paint a rather favorable picture for life subsisting on a moon 750 million miles away. "This is the first evidence of ongoing hydrothermal activities existing outside of the planet Earth," said Hsu. "If the conditions down there are as we suggested, then it seems to be a habitable environment." (*Nature*)

—Adam Hadhazy

Green Light

Out of more than 100,000 species of fungi known worldwide, only 71 glow in the dark. Just why these rare bioluminescent mushrooms emit their eerie greenish light has long puzzled scientists. Now a new study offers a compelling answer.

Jay C. Dunlap of Dartmouth University in New Hampshire and six researchers focused their investigation on a particularly large, bright species, *Neonothopanus gardneri*, found in the tropical moist forest of Eastern Brazil. The scientists first grew the fungus in the lab for four days under a twelve-hour-light, twelve-hour-darkness cycle, mimicking daytime and nighttime, and then placed them in total darkness for six days.

A series of photographs revealed that the fungus continued to glow only at "night." Furthermore, the researchers found that levels of luciferin, luciferase, and reductase—molecules in the bioluminescence system that interact to produce light—also peaked at night. The timing of this lights-on, lights-off activity strongly suggests that the

By day and night: Mushrooms of Neonothopanus gardneri *grow on the base of a babassu palm in the Coconut Forest of Altos, Piauí State, Brazil*

bioluminescence runs on a circadian clock. Such clocks, built into many organisms, regulate daily rhythms, keeping their own time under constant conditions but taking cues from the environment, such as light and temperature. The finding "dispels the idea that bioluminescence in these mushrooms 'just happens,'" said Dunlap. "It is clearly meant to happen."

To test a possible adaptive function for bioluminescence, the researchers fabricated acrylic resin "mushrooms" and placed green LED lights inside them, closely mimicking the fungi's signature radiance. Thirty-eight faux mushrooms—half of them lit up and half kept dark as controls—were placed in the forest. A sticky coating was applied on them to trap insect visitors.

The glowing mushrooms drew in forty-two insects—including ants, flies, rove beetles, true bugs, and wasps—while the controls caught just twelve. According to Dunlap, it seems "extremely likely" that the beguiled insects might aid the mushrooms' reproduction by carrying spores on their bodies or inside their guts.

"The notion that bioluminescence would attract insects that could help in spore dispersal has always been appealing, but no one ever did the experiment," said Dunlap. University of São Paulo coauthor Cassius V. Stevani added that in his opinion, "The debate at least for this subject is over." (*Current Biology*)

—A. H.

Eagle Eyes on Eagle Toes

In 2013 paleoanthropologist Davorka Radovčić was sorting through a collection of Neanderthal and animal remains at the Croatian Natural History Museum in Zagreb, Croatia, when some eagle talons caught her eye. The white-tailed eagle bones, excavated more than a century ago at a well-known Neanderthal archaeological site near Krapina, Croatia, clearly displayed cut marks, previously unnoticed. Along with two Croatian colleagues, Radovčić invited fellow paleoanthropologist David W. Frayer of the University of Kansas to scrutinize the manipulations on these eagle bones—and their implications for Neanderthals' creative abilities.

Under a microscope, the eight talons and a single toe bone, which came from at least three adult eagles, yielded evidence that Neanderthals not only used the bones 130,000 years ago, but did so for symbolic purposes—the creation of ornaments they wore as jewelry. Four talons and the toe bone, which connects to one of the talons, revealed numerous V-shaped cuts, often in parallel and close to where eagle talon meets toe. They matched the patterns made by stone tools and, according to the researchers, likely resulted from efforts to separate claw from foot. The sharp edges of many of the cuts had been smoothed down. Based on the locations of the smoothed areas, the team proposes that the talons were fastened together with sinew or fiber as part of a necklace or bracelet, and that the polishing was the result of rubbing against other talons over time.

Some researchers argue that Neanderthals could not think symbolically, or only imitated such behavior from modern humans. But modern humans probably migrated into Europe only 50,000 years ago. The presence of so many talons from such a rare, aggressive bird and the nature of their alterations, long before the arrival of *Homo sapiens*, offers new support for the cultural sophistication of Neanderthals. (*PLoS ONE*) —*Ashley Braun*

Collection of eight talons and one phalanx from Krapina

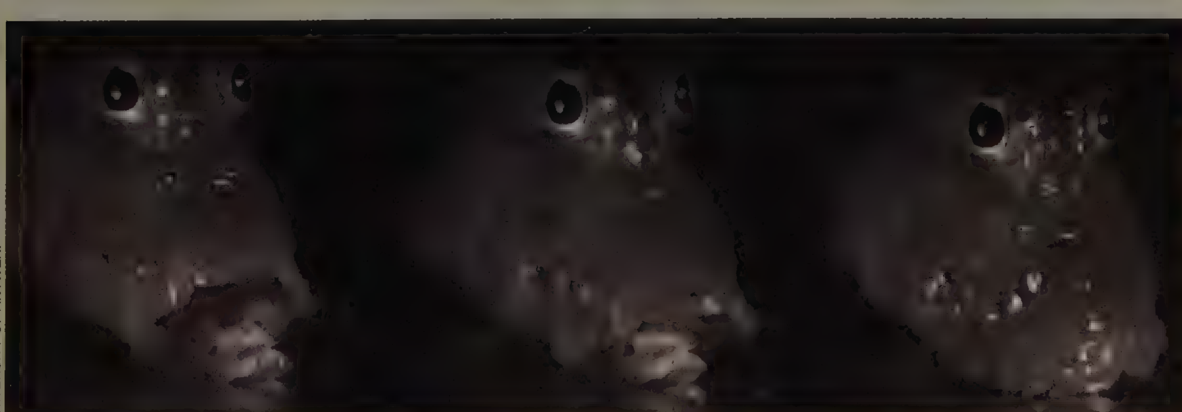
LUKA MJEDA, ZAGREB

Suck It Up

Between about 400 million and 350 million years ago, four-limbed vertebrates emerged from the ocean and colonized land. But feeding on land is vastly different from feeding underwater, which requires fish to expand their mouth cavities to suck food and surrounding water down their gullet. Krijn B. Michel at the University of Antwerp, in Belgium, and three colleagues sought out signs of adaptation to the constraints of eating on land in modern fish that straddle this water-land boundary.

The team examined feeding practices of Atlantic mudskippers, *Periophthalmus barbarus*, which hunt insects and crustaceans along muddy riverbanks. First, they used high-speed video to record four mudskippers as they used a transparent ramp to reach and gobble shrimp bits placed on a dry "bank" alongside the water in an aquarium. Next, they repeated the experiment with X-ray video, which enabled them to measure the movement of the top and bottom jaws, the hyoid (mouth floor), and the skull roof. For comparison, they recorded high-speed X-ray video of a typical suction-feeding fish—the pumpkinseed sunfish, *Lepomis gibbosus*—and an amphibious tetrapod, the Italian crested newt, *Triturus carnifex*, both while feeding. They also measured the resting volume of cavities involved in feeding by means of computed tomography (CT) scans of a mudskipper's head.

Slowing down the mudskippers' munching revealed the key to their land-based feeding: spitting out and sucking in mouthfuls of water. The researchers dubbed this a "hydrodynamic tongue." In reverse of the way most fish feed, as mudskippers approach prey on land, they elevate the floor of the mouth and pull in the gill covers, forcing water out of the open mouth onto the prey. After the mouth has encircled the food, they drop the mouth floor, expanding the gill covers and sucking water and prey through the mouth to the esophagus. When researchers placed absorbent material under the prey, preventing mudskippers from pulling the expelled water back in, fish failed to swallow prey 70 percent of the time. The timing and sequence of mouth floor movements in mudskippers was more similar to newts, which employ real tongues to capture and swallow food, than to suction-feeding sunfish. The mudskipper's behavior is thus a potential precursor behavior, probably displayed by the first tetrapods to feed on land. (*Proceedings of the Royal Society B*) —*A. B.*



MICHEL & VAN WASSENBERGH, FUNMORPH LAB, UNIVERSITY OF ANTWERP

Images from a high-speed video of an Atlantic mudskipper using its "hydrodynamic tongue"

The Shining


JON BENNIE/UNIVERSITY OF EXETER

"Mesocosms" at night

The effects of artificial light on the physiology and behavior of plants and animals are widespread. Take moths, which frantically fly around streetlights at night. The attraction of bats and other predators to light-lured moths should be a hint that such effects cascade through ecological communities. Little is yet known, however, about how artificial light changes species' interactions with each other.

At the United Kingdom's University of Exeter, five researchers, including ecologist Jonathan Bennie, investigated the impacts of artificial light on experimental communities of plants and insects. They were motivated in part by the current transition across the UK and other European countries from older-style amber streetlights to light-emitting diodes (LEDs), which produce a bluer-tinged, whiter light.

The researchers wondered whether artificial lighting impacts communities via bottom-up effects (enhancing or reducing plant growth and consequently the availability of food), top-down effects (changing the chances of predators or parasites finding prey or hosts), or via other mechanisms such as competition or behavioral shifts—for instance, skewing the tendency of insects to fly toward a source of light. The team set up fifty-four "mesocosms," containers tented with mesh in which natural communities were replicated. The mesocosms, about 3 x 3 x 1.5 feet each, were placed above the ground in an outdoor setting. Each received amber light, white light, or no light during the night. Those treatments were applied at three different levels of community complexity: plants only; plants and herbivores; and plants, herbivores, and predators. The plants were eighteen common grassland species, which, in the plant-only experiment, were sprayed regularly with insecticide. The plant and herbivore treatment had, in addition, aphids and slugs. The same assemblage plus two species of insect predators—ladybugs and ground beetles—formed the most complex mesocosms.

The results showed that both types of artificial light, but especially amber, suppressed flowering in *Lotus pedunculatus*, a plant species favored by the herbivores. That meant fewer tasty flowering shoots available, and consequently fewer herbivores—they had less to eat. The conclusions are based on just one field season of an experiment in which predators proved tricky to count. Nevertheless, the results point to resource availability (a bottom-up effect) rather than predation as the drivers of the light effects. As far as pinpointing the mechanism by which artificial light suppresses flowering, that's science that has yet to blossom. (*Philosophical Transactions of the Royal Society B*)

—*Lesley Evans Ogden*

THE WARMING EARTH

Water Shed

Alaska's Barrow Peninsula is the northernmost tip of the United States. Aside from the small city of Barrow, it is mostly a flat wilderness of permafrost tundra, marked by long, cold winters and short, cool summers. The peninsula is dotted with thousands of shallow lakes and ponds, mostly oblong in shape. A new study shows that these ponds have been steadily shrinking in number and size.


CHRISTIAN G. ANDRESEN

Aerial view of disappearing small ponds

Christian G. Andresen and Vanessa L. Lougheed of the University of Texas at El Paso gained access to previously classified high-resolution aerial imagery from 1948 and compared it with satellite images from 2002, 2008, and 2010. Concentrating on the months of July and August, the peak growing season in the region, they identified 2,855 ponds in their 100-square-mile study area in 1948, covering a combined area of more than 400 acres. For 2010, they counted 2,367 ponds, whose total area had declined by around 30 percent, to 280 acres. Noting that some ponds had split into two or more ponds as they shrank, the researchers conservatively concluded that, in sum, the number of ponds had decreased by up to 17 percent, while the size of ponds had shrunk by an average of one-third.

Andresen and Lougheed identify several factors, driven by the climate, as possible causes of the diminishing ponds. These included increased evaporation due to rising temperatures, greater infilling by plant life, and degradation of the underlying permafrost. Summer temperatures have risen significantly over the past fifty years, they say, with minimal increase in precipitation. The dominant types of sedges and other plant life growing in and around ponds have also changed over time, resulting in shrinkage of pond areas. Thawing permafrost below ponds due to higher water temperature may also lead to draining of those ponds.

Traditionally, says Andresen, Arctic ponds have tended to enlarge over time and merge to form lakes; if ponds continue to shrink, there will eventually be no lakes in the Barrow Peninsula. Besides upsetting carbon and energy budgets, this could affect the breeding cycle of such threatened bird species as the spectacled eider and the Steller's eider, ducks that feed and nest there. (*Journal of Geophysical Research: Biogeosciences*)

—*Harvey Leifert*

Natural Selections

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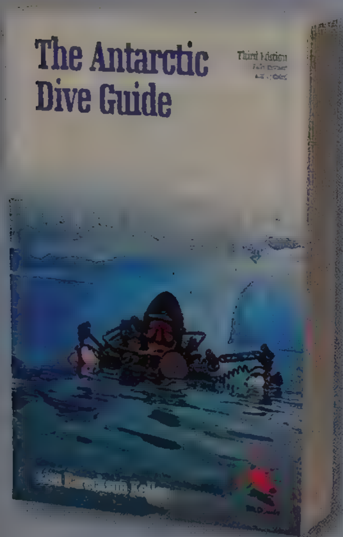

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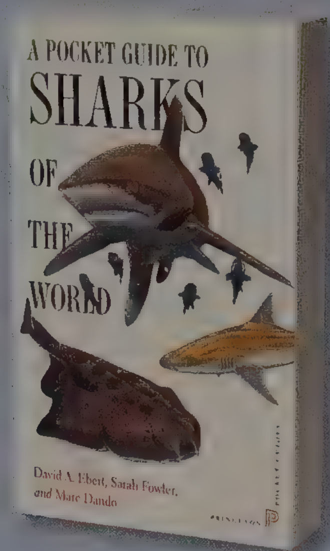

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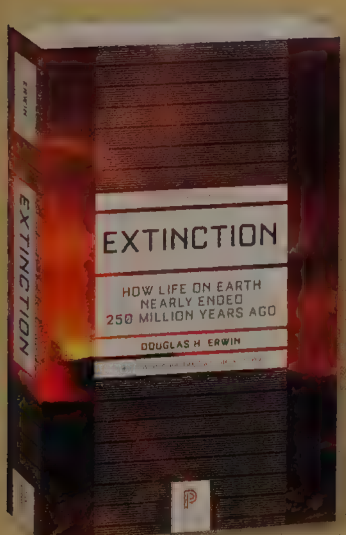

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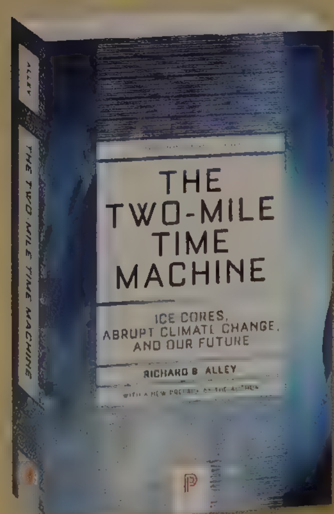

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NATURALIST AT LARGE

Curious Yellow

A foray into iris behavior

By Bernd Heinrich

Yellow iris, *Iris pseudacorus*, with an unopened bud at left and a spent flower at right

BERND HEINRICH

Behavior by a plant seems like a contradiction in terms. Animals can react quickly to environmental stimuli, and their reaction by movement qualifies as behavior. Plants generally react so slowly we don't even notice, though there are well-known exceptions, such as the Venus flytrap, which closes to snare insects, and *Mimosa pudica*, whose leaves fold up when jostled by a potential predator. Plants are also rooted in place, which limits their responses. Many, however, have evolved to recruit animals—especially insects, birds, and bats—to assist them, notably for pollination and seed distribution.

As in the mating game of animals, for fertilization to occur in most species of plants, each individual must contrive to get its pollen into the reproductive organ of another of its kind, and in turn to receive such pollen. Animal pollinators need to be rewarded for doing this work, typically with food. The reward must be sufficient but not overly generous. It must be ample enough to lure the pollinator to keep searching for other flowers of the same species, yet it must also be somewhat meager, or the pollinator might use an individual plant as a constant food provider and not move on to transfer pollen to (and from) other plants.

For each individual plant, it is also vital that the pollinator associate the reward with its type of flower—and not rub all the pollen off onto flowers of other species. Prominent identity tags for each plant species, provided by such characteristics as flower color, shape, and scent, assure that a rewarded pollinator tends to remain flower-faithful. As a consequence, plant species have competed to distinguish themselves from each other, evolving ever-greater differences in their blooms. In short, in handing the *behavior* part of their reproductive life over to animals, plants have generated displays that rival those of the birds of paradise.

One commonplace (but nonetheless gorgeous) example of floral art is the blue flag iris, *Iris versicolor*, widespread in New England wetlands. It has been a favorite of mine ever since, many years ago, I studied its pollination by bumblebees. Long-tongued bee species were the primary pollinators, and their reward was nectar. I shot pretty photographs of their intimate embraces with this flower. Another spectacular iris is *I. atrofusca*, a deep-black one found in the Judean Desert and nearby arid areas. My Israeli friend and fellow evolutionary ecologist Avishai Shmida introduced it to me. The species is pollinated by solitary bees that use the flowers as an overnighting den. The early morning sun heats the flowers, and so the bees sheltered inside them get warmed up and have a jump start on the day visiting other flowers. Reward enough! Meanwhile the plant possibly gains in water balance by not producing nectar. My northern bumblebees, in contrast, need sugar as a fuel to shiver and keep warm.

The yellow, or yellow flag, iris (*I. pseudacorus*), which grows in Europe, western Asia, and northwest Africa, is, like the North American blue flag iris, at home in wetlands. To my great surprise and pleasure I found a single plant of it in bloom directly along the shoreline of the Atlantic Ocean, on Star Island, at the border between New Hampshire and Maine. I could not resist taking a piece of its root and transplanting it. A lush plant of it now grows at my camp in Maine, and there in the summer of 2014 it flowered splendidly directly under my "shower" (a garden watering can that hangs from a sugar maple tree), a place where I spent days watching the nesting behavior of tree swallows in an adjacent bird box.

BERND HEINRICH

Watching swallows fly in and out of their box, I could not fail to notice the yellow iris plant. Day after day, and then week after week, it always had one or more large flower buds, one or more flowers that were open, and increasing numbers of curled-up spent flowers and seed capsules. Curiously, though, there never seemed to be a bud transitioning into a flower!

Something didn't add up—until one day when I glanced down and noticed a flower bud, and then, literally in the next moment, looked again and saw a fully open flower. It could not be magic. To find out what had happened, I then started to monitor the flowers more closely, to be there when others buds opened, and to make dissections to construct a working model of how a bud could move its parts to transform itself into full flower in a flash.

In all *Iris* species, the characteristic bloom, seen from above, is divided into thirds. Each third has a large drooping petal known as a "fall"; a vertical and often nearly equally showy petal called a "standard"; a stamen (comprising the male structures); and a pistil (the female structures). The fall has a greatly enlarged hanging lip and markings that serve as a "nectar guide," which helps orient pollinators on their way into a tubular chamber where they access the nectar. The roof of this tube is formed by the style, or shaft, of the pistil. In most flowers the style is a simple rod, but in irises it is flattened and flanged at the sides. The shaft bears the stigma, which receives pollen as a pollinator enters. As the pollinator passes it also picks up pollen from the anther, located under the style.

BERND HEINRICH

Crawling beneath the shaft of the flower's pistil, top, a bumblebee accesses nectar from a blue flag iris, I. versicolor. Above: Markings on one of a yellow iris's three falls, or large hanging petals, help guide any prospective pollinator.

An iris bud, in contrast to the flower, is a round and spike-like, with all the parts that will unfold into the triple array tightly wrapped inside.

Early in the flower-opening cycle of the yellow iris, I noticed that the stem holding the flower bud extend-

ed in length as the bud developed, so that the bud reached above the two leaf bracts that had surrounded it the day before. Subsequently, several hours before opening, the flower bud expanded near the base. A top view showed the three outer petals—the falls—curled into a swirl and wound around each other near their tips. When it happened, the opening of the bud took about one second, the three falls flying to the sides and down to nearly full extension, leaving the three "standards" upright.

The bloom remained fresh for two days, after which the petals again coalesced into a coil around each other and then shrank. The ovary grew and the remains of the petals dried and fell off. The blue flag iris followed the same general pattern, but lacked the "instant" flower-opening behavior.

The mechanism of flower opening and closing and other movement in plants, such as *Mimosa* leaf movements, involves volume changes in different compartments that expand or shrink as water is shifted in or out by osmosis, which depends in part on uptake of sugars after conversion from polysaccharide. However, both growth and osmotic pressure changes are gradual processes and do not explain the mechanics of *sudden* movement in *I. pseudacorus*. The snap of petal extension would require prior storage of energy, followed by a trigger mechanism for its release, perhaps similar to the way a number of plant species forcibly eject seeds: the common jewelweed (*Impatiens capensis*), for example, can throw seeds several yards from its fruit capsule.

Sudden movements resulting from release of stored energy are common in arthropods, including mantid shrimp (Stomatopoda), jumping spiders, and jumping insects such as fleas, flea beetles, leafhoppers, and springtails (as well as the backflipping click beetle). Slow muscle contraction stores energy in a mechanical spring, and then releases it by a trigger mechanism in analogy to a crossbow. A holding mechanism is required to store the energy. In the case of the yellow iris, the folded bud is apparently held in place by the fall petals, wrapped around each other near their tips. The stable position persists until sufficient force builds up to release the falls; as they start to slip over each other they open all the way [*see illustration at left*].

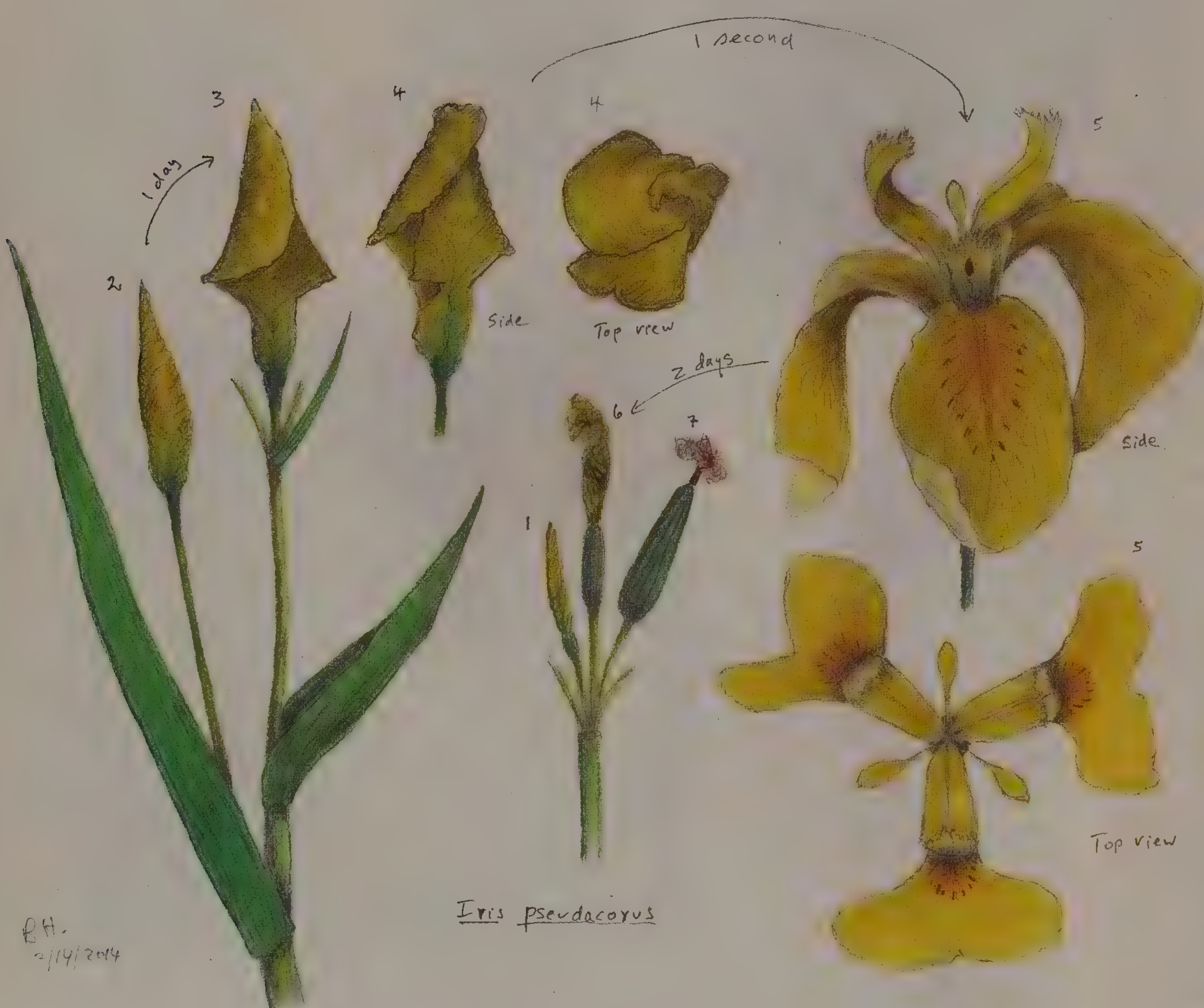


Illustration shows stages in the rapid unfurling of a yellow iris.

BERND HEINRICH

To my knowledge, among all irises, only the yellow species displays this instant-opening behavior. How might it have evolved that distinction? I can only speculate, but the place to start is with the flower's relationship with its pollinator.

Each flower's fall petal has two nectaries at its base, each yielding up to two microliters (that is, two millionths of a liter) of nectar, which is not enough to satiate a big bee but probably enough to stimulate her to search for another flower of the same kind. But not every bee reacts alike. A naive bee beginning her foraging career samples almost any kind of flower she comes in contact with. She becomes "converted" to a particular kind of flower (as well as to its plant's associated habitat) if she is

sufficiently rewarded. On the other hand, if she frequently encounters empty flowers of that type and in those locations, she will learn to avoid them and will prefer to visit others instead.

Perhaps the ancestors of the yellow iris became distributed in a very patchy way, say in scattered wetlands, where cross-pollination was difficult. Under that circumstance, it was crucial that bees attracted to the flower not be disappointed. One way to improve the odds was to make sure the flower didn't flash its signal until the reward was definitely in place.

When I told this thought to a friend, she immediately responded, "It's like a yard or estate sale—where you put up a huge sign to raise high expectations. But you can't put up the sign until *all* of the goods are out." As she pointed out, the most motivated customers try to get there first, streaming in before others. But if there's little on display, and they don't see something they want, they leave—and you lose them.

It's the same with an iris. Although the flower bud is itself potentially a big sign, a bee isn't likely to confuse it with the real sign, the open flower with its nectar guide. But if the flower petals open slowly, then it's like putting up the sign before the goods are available. Naive bee customers will come, look, see no nectar guide, no sign where the "door" is, and leave, never to heed that sign again.

As in other iris species, stranded individual yellow irises would still have reproduced vegetatively, by means of rhizomes—horizontal underground stems—creating patches of what really were clones. A big patch of clones would make cross-pollination even more difficult, because bees tend to stay in a good flower patch when they find one. Nevertheless, the yellow iris would keep open its option for sexual reproduction.

ORI FRAGMAN-SAPIR

The darkly colored I. atrofusca*, here growing in the Goral Hills of south central Israel, warms up quickly in the morning sun. A pollinating bee may use the bloom as an overnight shelter; it will then be rewarded with a warming jump start to the day, but no nectar.*

Since finding the yellow iris in New Hampshire, I now have clones planted at my home in Vermont as well as in three spots at my cabin in Maine. The plants do produce seeds, but there being no other "individuals" of the species around, that is from self-pollination, which results when a bee visits different members of the same clone or returns to the same plant when it opens a new blossom. We may even speculate that in the past, producing seeds by self-pollination in addition to growing vegetatively afforded the species some advantage. But in the long run, "selfing" is an evolutionary dead end.

A professor emeritus in the biology department at the University of Vermont, in Burlington, BERND HEINRICH *has specialized in the study of insect physiology and behavior and bird behavior. Among his books are* Life Everlasting: The Animal Way of Death *and* The Homing Instinct: Meaning and Mystery in Animal Migration *(Houghton Mifflin Harcourt, 2012 and 2014, respectively). His articles in* Natural History *include "Wasp Odyssey" (December 2012/January 2013) and, most recently, "Life in the Soil" (November 2014).*

Here Be Dragons

After maturing underwater, an insect takes flight.

Story and Photographs by Pieter van Dokkum

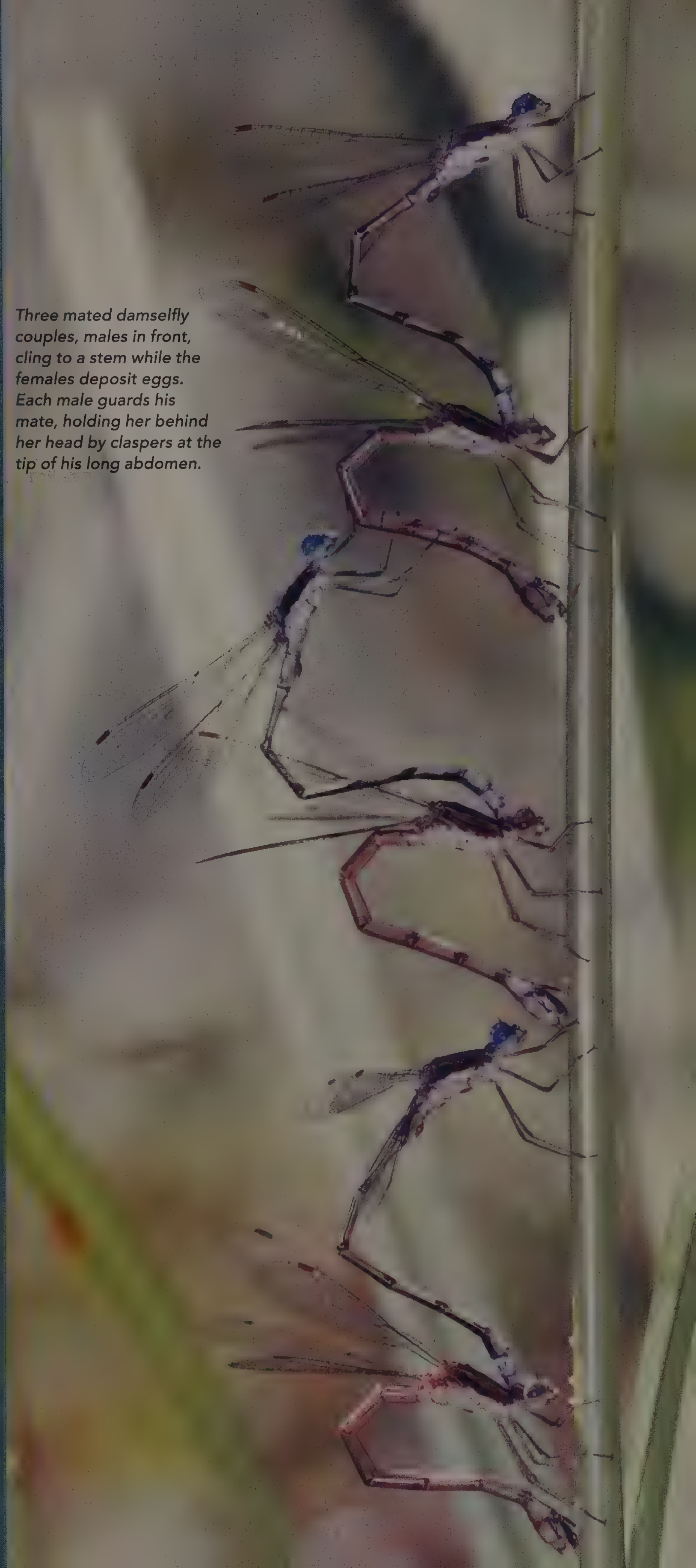
The four wings of a male flame skimmer can move independently, enabling it to hover and perform flight acrobatics, a trait common to all dragonflies.

In the course of the Earth's history many different types of animals have come and gone, responding to changes in climate, geology, the availability of appropriate food sources, and the rise and fall of other species. Some body plans are so successful, however, that they have endured virtually unchanged for millions of years. The shark is a famous example, having similar-looking ancestors dating back 400 million years. The dragonfly is in the same illustrious group and is thought to be one of the first flying animals, with ancestors appearing in the fossil record some 300 million years ago. The wingspan of some species reached an astonishing two and a half feet, probably owing to higher oxygen levels in the atmosphere and the absence of such predators as birds. These ancient giants were the largest insects that ever lived. If their immature, aquatic forms were still around today we would probably think twice before going in the water!

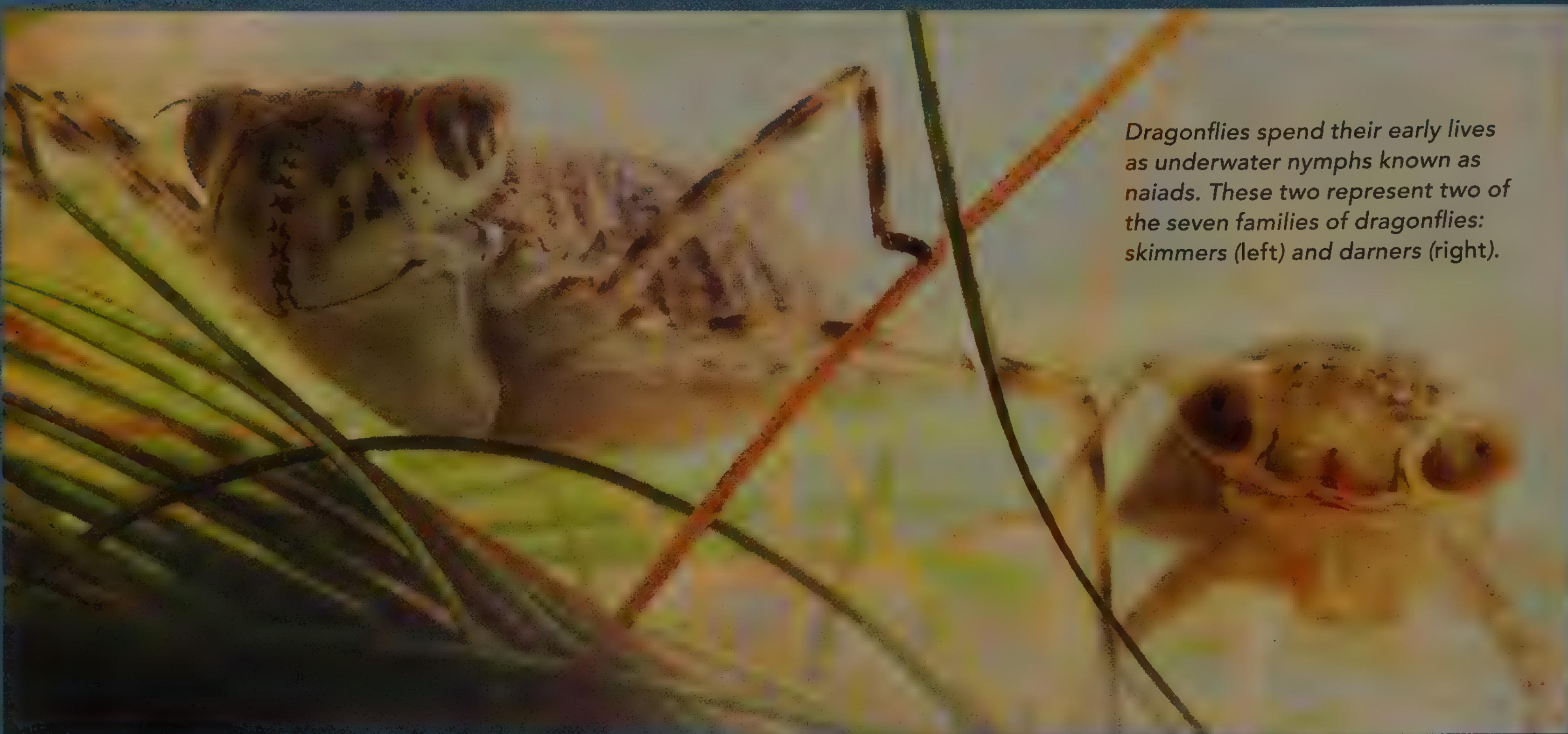
As with all insects, dragonflies, as well as their close cousins the damselflies, have an external skeleton and six legs arranged in three pairs. Their bodies are composed of three parts: the head, which is dominated by a pair of huge eyes; the thorax, the power center to which the legs and two pairs of wings are attached; and the abdomen, which can bend, as it is made up of ten segments. The head is mostly used for seeing and eating, the thorax for movement, and the abdomen for breathing, processing food, and reproduction.

Dragonflies and damselflies are members of the order Odonata, or "toothed ones," referring to their toothlike mandibles. The two groups have a similar adult body plan, but there are some important differences. Dragonflies are generally larger and stockier than damselflies. While resting, their wings remain spread, whereas many damselfly species fold their wings close to their bodies. Dragonflies have huge eyes that in many species touch at the top of their heads; damselflies have widely separated eyes.

Watching the flight of dragonflies is mesmerizing. Although they are most easily



Three mated damselfly couples, males in front, cling to a stem while the females deposit eggs. Each male guards his mate, holding her behind her head by claspers at the tip of his long abdomen.



Dragonflies spend their early lives as underwater nymphs known as naiads. These two represent two of the seven families of dragonflies: skimmers (left) and darners (right).

Having crawled out of its aquatic environment, a common green darner leaves behind its empty nymph shell, or exuvium, as it transforms into an adult dragonfly.

observed when stationary, dragonflies really are creatures of the air, and their bodies are made for flying. They can fly upside down, stop, and change direction in the blink of an eye; they can hover and then suddenly accelerate to speeds of up to thirty miles per hour. Their flight appears erratic, but after a while patterns emerge: a short hover near the edge of their territory; a backward flip to grab a gnat out of the air; a sudden acceleration when a rival is spotted; a furious ball of legs, wings, and jaws when the rival comes too close.

The flight of airplanes and birds is made possible by their curved wing shape, which generates upward pressure as air flows around it. Dragonflies use a different method: experiments have shown that they create and use turbulence in the air to get extra lift. The airflow around the wings is very complex, and its study may one day lead to new types of aircraft. Dragonflies are also able to move each of their wings independently, giving them great maneuverability. In normal flight the front wings usually lead the back wings, a method of flight called phased stroking. Other flight methods used by dragonflies are counterstroking, with one pair of wings going down while the other goes up, and synchronized stroking, with the four wings going up and down together.

Above streams and ponds, most of the actively flying odonates are male dragonflies, which are patrolling their territory or looking

for females. Damselflies have relatively small wings and are much less accomplished fliers than dragonflies; they usually hover close to the surface and spend a lot of time perching on plants near the water's edge. It is easy to overlook the humble damselfly as it slowly goes about its business inches above the water, while its more robust cousins are zooming overhead. Nevertheless, those who make the effort to observe these delicate, slender creatures will find they have a beauty—and a fierceness—all their own.

Ruby meadowhawks mate: The male dragonfly, on top, holds the female with the tip of his abdomen while she gathers sperm.

Do dragonflies sleep? At night they are motionless, with all bodily functions greatly diminished. Because the physiology of insects is so different from that of mammals, scientists are reluctant to describe this state as sleep, and have settled on the word "torpor" instead—although an observer would be forgiven for thinking that a dew-covered dragonfly on a cold morning is fast asleep. When the Sun comes up, the dragonfly will rub its eyes, removing the dew. It will slowly warm up, and as the dew evaporates and the wind picks up, it will take off for its first flight of the day.

Like most other animals, dragonflies spend a lot of time and energy to ensure the survival of their species. Males seem continuously preoccupied with finding a mate and compete aggressively, attacking rivals that enter their territories and keeping a constant eye out for females. Battles over females can be fierce, and even noisy: two males and a female can become a buzzing concentration of energy and motion as wings and legs beat against each other.

A female eastern pondhawk consumes her insect prey.

Before copulating, male dragonflies and damselflies grab the female behind her head, using claspers on the tip of the male's abdomen. The female then bends her abdomen, bringing the tip in contact with the abdomen of the male just behind the thorax. The couple now forms a wheel, which in damselflies is heart-shaped. Many dragonfly species copulate on the wing, continuing their flight as a twelve-legged, eight-winged circular creature.

After copulating, a female sets out to lay eggs, typically hundreds at a time. It is in the male's interest to make sure he was the last to copulate with the female before she lays her eggs. Some males guard the female, hovering over her while she lays her eggs; others take no chances and hold on to the female behind her head. Many different strategies are employed to enhance the chances that at least some of the offspring will survive. Female dragonflies in the large Libellulidae (skimmer) family usually deposit their eggs in the wa-

Male spangled skimmer: The female is brown with yellow stripes.

Male golden-winged skimmer, wings outspread as is typical of dragonflies, perches on the end of a stem near a pond, guarding its territory.

A widow skimmer: The white spots
t midwing show it is a male.

When perching, a male azure bluet, like most damselflies, folds its wings against its body.

ter, whereas those in the Aesnidae (darner) family and the damselflies typically carve slits in vegetation and place their eggs inside. Whether floating in the water or neatly tucked away in a plant stem, the eggs are now on their own.

Dragonflies and damselflies do not live long: the odonate life cycle in temperate climates is usually a year. Most of this time they spend underwater as nymphs (or naiads, to use the precise term), whose bodies grow and change in successive moltings. Once they metamorphose into their adult stage, odonates do not molt again. Their bodies, and particularly the delicate wings, are not made to last. The wings get damaged and torn in fights, and it is not unusual to see a dragonfly whose wings are shredded so much that flight no longer seems possible. The lifespan of an adult dragonfly is typically only a few months. In northern climates the lives of dragonflies can also be cut short by the onset of cold weather in the fall: odonates need warmth to power their muscles.

Old age is, of course, not the only cause of death. Dragonfly nymphs are an important food source for fish, crayfish, and waterbirds. Many dragonflies perish during metamorphosis, falling victim to spiders and other predators during this time of complete helplessness. Birds are often attracted to ponds when dragonflies are emerging in large numbers, and in the early morning hours they feast on the immature, fluttering insects. Although adult dragonflies are superb fliers, they too fall prey to such birds as barn swallows.

Individual dragonflies are ethereal creatures, whose wings beat only a short time. Look closely, however, and just a few feet from the floating body of a dead dragonfly you may see a damselfly laying eggs. Even in the dead of winter a nymph is scurrying on the bottom of a frozen pond, preparing for a future of light, air, and warm summer wind flowing over gossamer wings.

Excerpted from *Dragonflies: Magnificent Creatures of Water, Air, and Land*, by Pieter van Dokkum, published by Yale University Press. Copyright © 2015 by Yale University.

Pieter van Dokkum had been thinking of "capturing the beauty and mystery of dragonflies in photographs" for several years, but what made it practical was his discovery of a small pond not far from his home in New Haven, Connecticut. That pond, which abounded with dragonflies, yielded about a third of the images he chose for his book; he took other photographs elsewhere in Connecticut as well as in Arizona, California, Florida, Maine, Massachusetts, Michigan, New Mexico, North Carolina, and The Netherlands. Van Dokkum is the Sol Goldman Family Professor of Astronomy and Physics at Yale University, where his main research interest is to develop an understanding of how large galaxies are formed and how they evolve. In that capacity he takes images of the night sky.

JUNK Matters

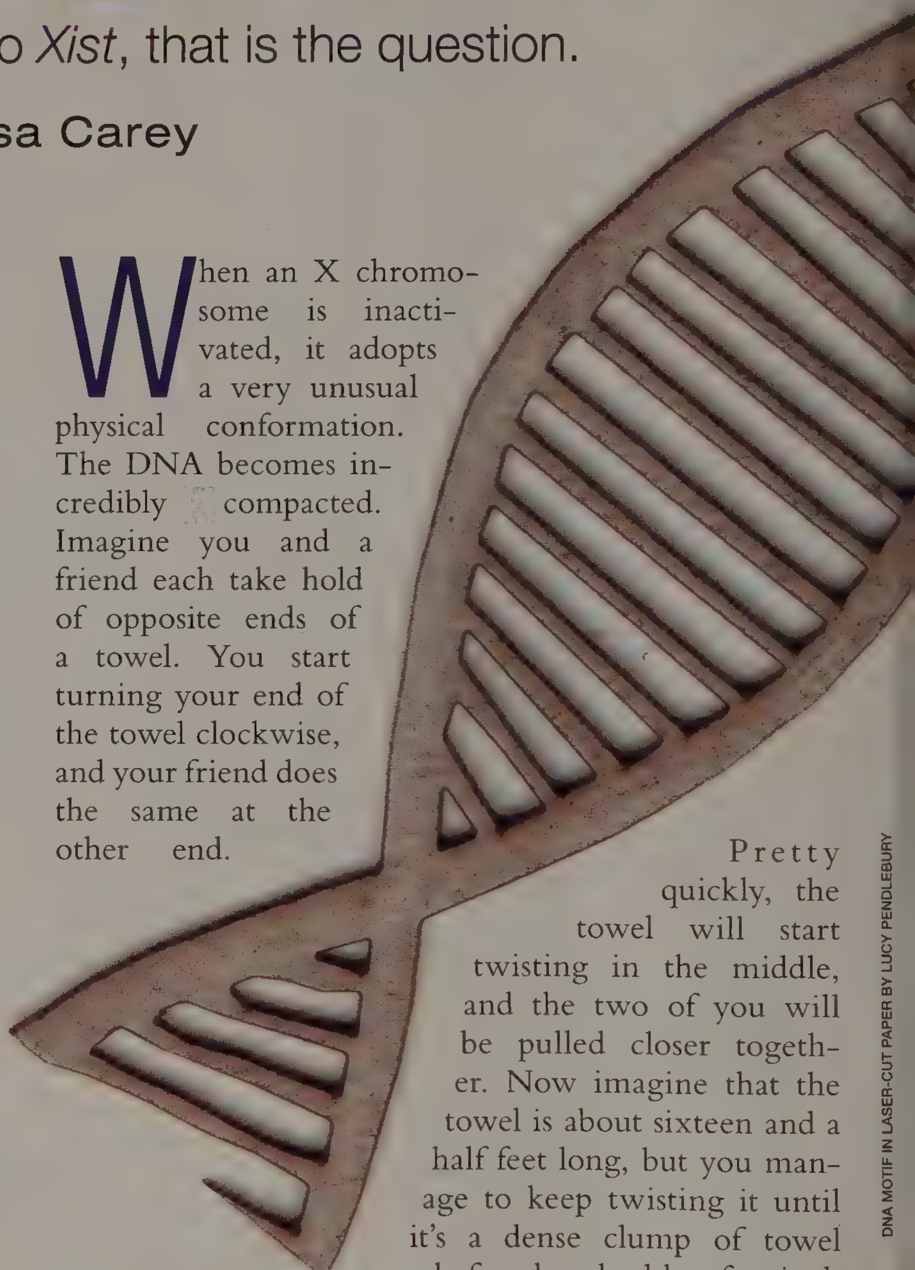
Part 3: To *Xist* or not to *Xist*, that is the question.

By Nessa Carey

In a twelve-month period from 2011 to 2012, 813,200 babies were born in the United Kingdom. Extrapolating from established rates of genetic disorders per live births, we can estimate that nearly 1,200 of these babies had Down syndrome; around 270 had a more severe condition, Edwards syndrome; and fewer than 120 had an even rarer and more severe developmental condition, Patau syndrome. All three conditions are caused by a full or partial extra copy of specific chromosomes in the genome. In a nursery of more than three-quarters of a million babies, 1,590 cots is a very small number. This number is consistent with the concept that having too many copies of a chromosome is very damaging: in general we would not expect high survival rates, either before or after birth, when it occurs.

Unfortunately, it seems cells do not have a way to shut down the extra chromosomal material to prevent its mischief. It's surprising to learn, therefore, that about half of the babies born in that period—that's over 400,000 children—routinely shut down a chromosome. Yes, one in two of us. It's the X chromosome. Females have two X chromosomes, and by a remarkably ingenious arrangement, within every cell, one or the other X chromosome is switched off. This is known as X inactivation, and it's a process that relies utterly on junk DNA.

One of the oddest things we have come to realize is that our cells can count their number of X chromosomes. Male cells contain an X and a Y chromosome, and they never inactivate the single X. But sometimes males are born who have two X chromosomes and one Y. They are still males, because it's the Y chromosome that drives masculinization. But each of their cells inactivates one of its two X chromosomes, just as female cells do.



DNA MOTIF IN LASER-CUT PAPER BY LUCY PENDLEBURY

When an X chromosome is inactivated, it adopts a very unusual physical conformation. The DNA becomes incredibly compacted. Imagine you and a friend each take hold of opposite ends of a towel. You start turning your end of the towel clockwise, and your friend does the same at the other end. Pretty quickly, the towel will start twisting in the middle, and the two of you will be pulled closer together. Now imagine that the towel is about sixteen and a half feet long, but you manage to keep twisting it until it's a dense clump of towel only four hundredths of an inch in length. That's how tightly compacted the X chromosome becomes. One of the consequences is that it can be seen when looking at the nucleus of a female cell under a microscope, whereas all the other chromosomes are long and stringy and can't be visualized. The condensed X chromosome is called the Barr body.

In order to try to understand how X chromosome inactivation happens, scientists studied unusual cell lines

and mouse strains. These focused on examples where parts of the X chromosome had been lost, or where bits of it had been transferred to other chromosomes. Some cells that had lost part of the X chromosome were still able to inactivate one of their X chromosomes, as shown by the presence of the Barr body. But cells that had lost a different part of the X weren't able to form Barr bodies, showing that they hadn't inactivated a chromosome.

In addition, where parts of the X chromosome were transferred to other chromosomes, sometimes those abnormal chromosomes were inactivated, and other times they weren't. It all depended on which bit of the X chromosome had been transferred.

These data enabled researchers to narrow down the region on the X chromosome that was key for inactivation. Rationally enough, they called this region the X inactivation center. In 1991, a group reported finding a gene in this region of DNA that they called *Xist*—for *X-i*nactive *s*pecific *t*ranscript. In a pair of equivalent X chromosomes, one is inactivated and one is not. The team found that only the *Xist* gene on the inactive X expresses *Xist* RNA. As far as scientists knew at the time, most RNA served as an intermediate step in manufacturing a protein. So the next question was to sequence the *Xist* gene's RNA molecule and predict the amino acid sequence it encoded.

Xist RNA is very long, about 17,000 bases. Each amino acid is encoded by a block of three bases, so a 17,000-base RNA could theoretically code for a protein of over 5,700 amino acids. But when the *Xist* RNA sequence was examined, the longest run coding for amino acids was just under 300. This despite the fact that the *Xist* RNA was presumably spliced: when messenger RNA is transcribed from DNA, it's pieced together from only the protein-coding stretches, omitting all the intervening junk sequences. The "problem" was that they found *Xist* RNA to be liberally scattered with sequences that don't code for amino acids, but that act as stop signals when protein chains are being built up. This is a little like trying to build a tall tower out of Lego blocks, which is perfectly straightforward until someone hands you one of those roof bricks that doesn't have any of the attachment nodes on the top. Once you insert that brick, your tower can't get any bigger.

If *Xist* did encode a protein, it would seem very odd that a cell would go to the effort of copying 17,000 base pairs of DNA into RNA to produce a protein that could have been encoded by a far shorter length of RNA. Very soon, researchers in the field realized that the reality was even stranger than this.

DNA is found in the nucleus. It's copied to form RNA, and then messenger RNA is transported out of the nucleus to structures where it acts as a template for protein assembly. But analyses showed that *Xist* RNA never leaves the nucleus. It doesn't encode a protein, not even a short one. *Xist* was in fact one of the first discovered of many examples of an RNA molecule that is functional on its own terms, not as a carrier of information about a protein. It's a great example of how junk DNA—DNA that doesn't lead to production of a protein—is anything but junk.

An odd feature of *Xist* is not just that it doesn't leave the nucleus. It doesn't even leave the X chromosome that produces it. Instead, it essentially sticks to the inactive X and then spreads along the chromosome. As more and more *Xist* RNA is produced, it begins to cover the inactive X chromosome, in a process quaintly referred to as "painting." No one really knows the physical basis of how the *Xist* RNA creeps along the chromosome, like the mile-a-minute vine covering a wall. We do know that if the X inactivation center is transferred onto an autosome, or non-sex chromosome, then the autosome can be inactivated as if it were an X.

Although *Xist* is required to initiate the process of X inactivation, it has helpers that strengthen and maintain the process. As *Xist* paints the X chromosome, it acts as an attachment point for proteins in the nucleus. These bind to the inactivating X, and attract yet more proteins, which shut down expression even more tightly. With very few exceptions (mostly at the very tips of the chromosome arms, and mostly genes that have matches on the Y chromosome), the only gene that isn't coated with *Xist* RNA and

these proteins is the *Xist* gene itself. It remains a little beacon of expression in the chromosomal darkness of the inactive X. So we have here a situation where a piece of "junk" DNA—one that doesn't code for protein—is absolutely essential for the function of half the human race.

Scientists have recently discovered that this process of X inactivation requires at least one other piece of junk DNA. Confusingly, this is encoded in exactly the same place on the X chromosome as *Xist*. DNA is composed of two strands (the iconic double helix). The machinery that copies DNA to form RNA always "reads" DNA in one direction, which we could call the beginning and end of a specific sequence. But the two strands of DNA run in opposite directions to each other, a little like one of those funicular railways we find at older seaside and mountain resorts. This means that a particular stretch of DNA may carry two lots of information, running in opposite directions to each other.

The other key piece of junk DNA involved in X inactivation is called, rather fittingly, *Tsix* (*Xist* spelled backwards). It is found in the same region as *Xist* but on the opposite strand. *Tsix* encodes an RNA of 40,000 bases in length, more than twice the size of *Xist*. As with *Xist*, *Tsix* never leaves the nucleus.

Although *Tsix* and *Xist* are encoded on the same part of the X chromosome, they are not expressed together. If an X chromosome expresses *Tsix*, this prevents the same chromosome from expressing *Xist*. This means that *Tsix* must be expressed by the active X chromosome, unlike *Xist*, which is always expressed from the inactive one. This mutually exclusive expression of *Tsix* and *Xist* is determined early in development.

Before fertilization, the egg has one X chromosome, and the sperm has an X or a Y. The X chromosome in the egg, even if it was an inactive one in the mother, will have been reactivated and will have lost any of the protein marks that show it was ever inactivated, and the X chromosome in the sperm has never been inactivated. Following fusion of the egg and sperm and six or seven rounds of cell division, there will be a hundred or so cells in the embryo. It's at this stage that each cell in a female embryo randomly switches off one of its two X chromosomes.

This requires a fleeting but intense physical relationship between the pair of X chromosomes in a cell. For a couple of hours, the cell's two X chromosomes are associated over the X inactivation center, which codes for both *Xist* and *Tsix* RNA. The encounter ends with one of the X chromosomes being inactivated. The decision that gets made is then maintained for the rest of life, not only for that cell but also for its trillions of daughter cells.

ANDREAS BOLZER, GREGOR KRETH, IRINA SOLOVEI, DANIELA KOEHLER, KAAN SARACOGLU, CHRISTINE FAUTH, STEFAN MÜLLER, ROLAND EILS, CHRISTOPH CREMER, MICHAEL R. SPEICHER, THOMAS CREMER

The twenty-three pairs of chromosomes in a human female, including the two X chromosomes, have been isolated from a dividing cell, when the chromosomes are most compact. The fluorescent colors result from a process to evaluate the DNA.

It's still not entirely clear what happens during the hours of X chromosome intimacy in early development. The current theory is that there is a reallocation of junk RNA between the two chromosomes, such that one ends up with all the *Xist* and becomes the inactive X. We don't know how, but it's possible that one chromosome expresses slightly more or less of *Xist* or another key factor. We do know that the process begins just as levels of *Tsix* start to drop. It may be that once the *Tsix* level falls below a certain critical threshold, *Xist* can start getting expressed from one of the X chromosomes.

X inactivation is entirely dependent on "junk" DNA, and really gives the lie to that terminology. The process is absolutely essential in female mammals for normal cell function and a healthy life. It also has consequences in various disease states. Full-blown fragile X syndrome of mental retardation only affects boys. That is because the implicated gene is carried on the X chromosome. Women have two X chromosomes. Even if one of their chromosomes carries the fragile X mutation, enough protein is produced in the cells where the normal X chromosome is the active one to avoid the worst of the symptoms. But males possess only one X chromosome; their Y chromosome is very small and doesn't carry many genes apart from the sex-determining ones. Consequently, they can't compensate if

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Human female's white blood cell showing a drumstick-shaped Barr body (arrow), a compacted form of an X chromosome that has been inactivated. The three larger areas with darkened contents are lobes of the cell's nucleus, here seen in cross section. The Barr body has been extruded to the periphery of the nucleus.

their sole X chromosome carries the fragile X mutation.

This is also true of a whole range of genetic disorders where a mutated gene is carried on the X chromosome. Relevant medical conditions range from relatively mild issues, such as red-green color blindness, to much more severe diseases, such as hemophilia B, the blood clotting disorder. Queen Victoria was a carrier of the latter condition, and one of her sons (Leopold) was a sufferer and died at the age of thirty-one from a brain hemorrhage. Because at least two of Victoria's daughters were also carriers, and the royal families of Europe tended to intermarry, this mutation was passed on to various other dynasties, most famously the Romanov line in Russia.

Although women carrying the mutation that causes hemophilia only produce 50 percent of the normal amounts of the clotting factor, this is enough to protect them from symptoms. That is partly because this clotting factor is released from cells and circulates in the bloodstream, where it reaches high enough levels for protection against bleeds, no matter where they happen.

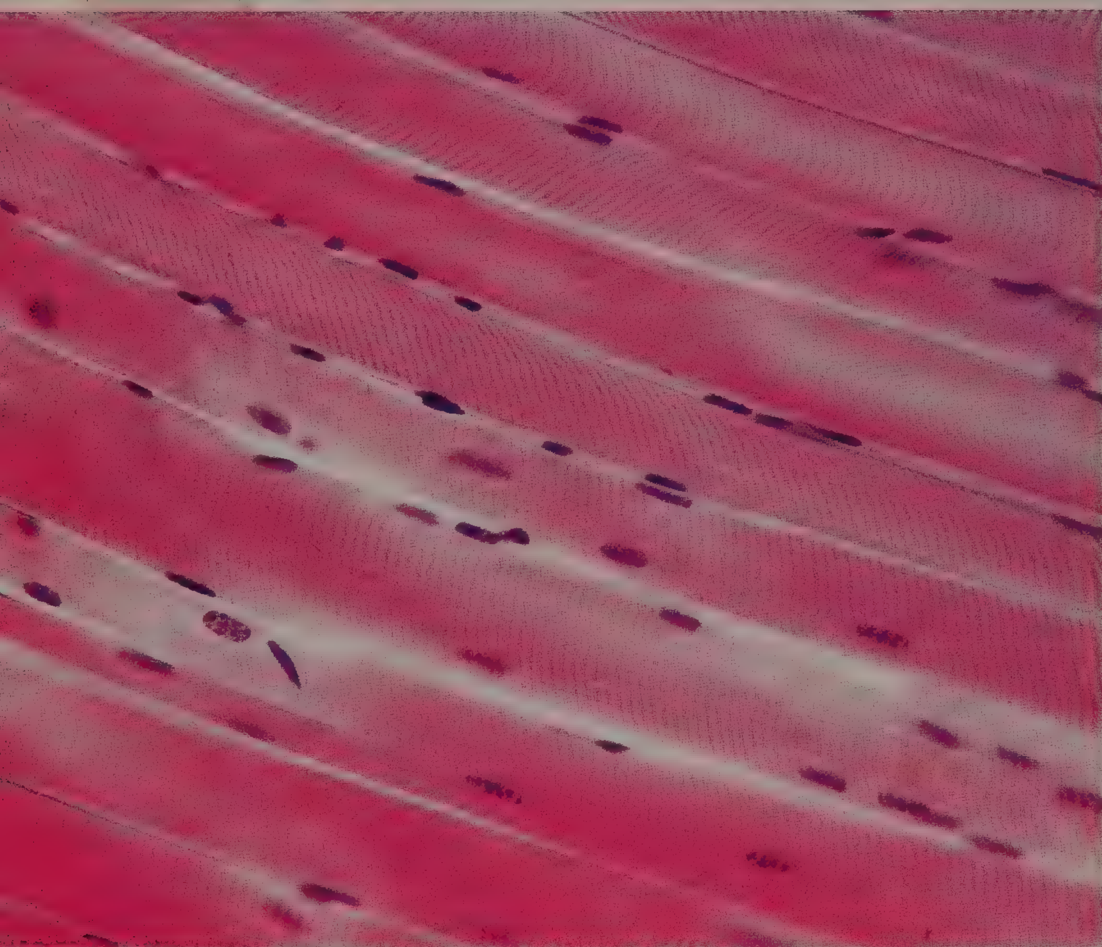
There are circumstances, however, in which the presence of two X chromosomes in a woman doesn't guarantee protection from an X-linked disorder. Rett syndrome is a devastating neurological disease that presents in some ways as a really extreme form of autism. Baby girls appear to be perfectly healthy when born and they reach all the normal developmental milestones for the first six to eighteen months of life. But after that, they begin to regress. They lose any spoken language skills they have developed. They also develop repetitive hand actions, and lose purposeful ones such as pointing. The girls suffer serious learning disability for the rest of their lives.

Even though an affected female has one normal copy of the gene in question, and on average half of the cells in her brain express normal amounts of the corresponding protein, it's not sufficient to overcome the deficit. Rett syndome pretty much only affects girls. This is unusual for an X-linked disorder, where girls are usually carriers and boys are affected. This might make us wonder how boys are protected from the effects of a Rett mutation. But the reality is that they are not. The reason we almost never find boys with Rett syndrome is because affected male embryos don't develop properly and the fetuses don't survive to term.

Duchenne muscular dystrophy is a severe muscle-wasting disease. Boys with this disorder are fine initially, but during childhood their muscles begin to degenerate in a characteristic pattern. For example, in the legs the thigh muscles begin to waste first. The boys develop very large calves as their bodies try to compensate, but after a while those muscles also wither. The children are usually wheelchair users by their teens, and the average life expectancy is only twenty-seven years of age. The early mortality is caused to a large extent by the eventual destruction of the muscles involved in breathing.

Duchenne muscular dystrophy is caused by a mutation in a gene on the X chromosome that encodes a large protein

called dystrophin. This protein seems to act as a sort of shock absorber in muscle cells. Carrier females will usually produce 50 percent of the normal amounts of functional dystrophin protein. This is generally sufficient, because of an odd anatomical feature. As we develop, individual muscle cells fuse to create large super-cells with lots of individual nuclei in them. This means each super-cell has access to multiple copies of the necessary genes, from different nuclei. So the muscles of carrier females overall contain enough dystrophin protein for normal activity, instead of one cell with enough and one cell with none.



Skeletal muscle super-cells contain many nuclei. In a female, commonly some of the nuclei will have one X chromosome inactivated while other nuclei have the other X inactivated. Both X chromosomes therefore have active representation in the super-cell, which can ameliorate certain diseases carried on the X chromosome if some nuclei have an active normal copy of the gene.

There was an unusual case, however, of a woman with all the classic symptoms of Duchenne muscular dystrophy. This is very rare, but there are ways we could predict this would happen. One possibility would be if her mother was a carrier and her father was a Duchenne sufferer who survived long enough to have a child. If that was the case, the daughter would definitely have inherited a mutated gene from her father, and there was a one-in-two chance that the egg produced by her mother also contained a mutated dystrophin gene.

But the doctors treating this patient had taken a family history, and they knew that her father didn't have Duchenne muscular dystrophy, so another explanation was necessary. Sometimes mutations arise quite spontaneously when eggs or sperm are produced. The gene that codes for dystrophin is very large, so it is at relatively high risk of mutation compared with most other genes in the genome. It would seem like quite a good bet that this female inherited a mutated chromosome from her carrier mother, and a new mutation in the sperm that fertilized the egg.

There was only one problem. The patient had an identical twin sister, derived from the very same egg and sperm. *And her twin sister was absolutely healthy.* No symptoms of Duchenne muscular dystrophy at all. How could two women who were genetically identical differ so much with respect to a genetically inherited disorder?

Think back to those hundred or so cells that undergo X inactivation during early embryonic development. About 50 percent of them will switch off one X chromosome, and the remainder will switch off the other one. The sister with Duchenne muscular dystrophy was simply incredibly unlucky during this stage. By sheer chance, almost all the cells that would ultimately give rise to muscle switched off the normal copy of the X chromosome, the one inherited from her father. This meant that the only X chromosome switched on in most of the nuclei in her muscle super-cells was the faulty one from her carrier mother. So very few of the affected twin's muscle cells were able to express dystrophin, and she developed the symptoms normally only seen in males.

When her genetically identical twin was developing, however, some of the cells that would give rise to muscle switched off the normal X chromosome and some switched off the mutated one. This meant that her muscles expressed enough dystrophin to keep them healthy, and she was an asymptomatic carrier, just like her mother. This was all caused by a simple fluctuation in the distribution of *Xist*, a long bit of RNA derived from junk DNA. The fluctuation lasted no more than a couple of hours, and occurred over a distance considerably less than a millionth of the diameter of a human hair. Yet it was the difference between winning and losing in the health lottery.

LEONARDO BOIKO

Tortoiseshell or calico cats—here, two calico sisters—are almost always females, and their markings in orange and black, or similar colors, depend on which X chromosome is inactivated in different groups of cells. The inactivation process occurs randomly after the fertilized egg has already begun to divide, so its results cannot be predicted on the basis of the DNA alone. A cloned calico cat grown from donor DNA will therefore not be colored just like its donor.

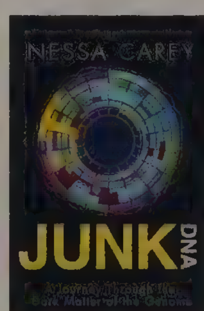
It is perhaps even stranger to think that some of the cat lovers among us look at, and stroke, the consequences of X inactivation every day. Tortoiseshell and calico cats are the ones with the distinctive patterns of orange and black. These coat colors occur in patches. The gene that controls the coat color comes in two forms. An individual X chromosome carries either the orange version or the black version.

If the X chromosome carrying the black version is inactivated, the orange version on the other chromosome will be expressed, and vice versa. When the cat embryo is at the size of a hundred cells or so, one or the other X chromosome will be inactivated in each cell. And just as in all the other examples, all the daughter cells will switch off the same X chromosome as their progenitor. Eventually, some of these daughter cells will give rise to the cells that create pigment in the fur. As more and more of these cells divide and develop, descendants of the same cell stay close to each other. This means that daughter cells tend to be clustered in patches. Because of the pattern of X inactivation in the daughter cells, this will lead to patches of orange fur and patches of black fur.

In 2002 scientists demonstrated beautifully just how random the process of X inactivation really is, by cloning a calico cat. They took cells from an adult female cat, and carried out the standard (but still fiendishly tricky) process of cloning. To do this, they removed the nucleus from the cell of the adult cat and put it into a cat egg whose own chromosomes they'd removed. This egg was implanted into a surrogate cat mother, and a lively and beautiful female kitten was born. And she wasn't colored anything like the genetically identical cat of which she was a clone.

When the nucleus from the mother cat was put inside a cat egg, the egg caused changes to the chromosomes. One of these changes was the removal of the inactivating proteins on one of the X chromosomes, and the switching off of *Xist* expression. Consequently, as the embryo developed, it went through the normal process at around the hundred-cell stage, randomly inactivating an X chromosome in each cell. The pattern of X inactivation was passed on to daughter cells in the standard way, and the kitten developed a different distribution of orange and black fur from its clonal "parent."

The moral of this story? If you have a calico cat you think is exceptionally beautiful, take lots of videos, lots of photos, and if you want to be very weird about it, call in a taxidermist when she dies. But if you are ever approached by a door-to-door traveling cloner, just say no.



This is the concluding installment of Nessa Carey's foray into the mysteries of junk DNA, following installments in the March and April 2015 issues.

Excerpted from *Junk DNA: A Journey Through the Dark Matter of the Genome*, by Nessa Carey, (Columbia University Press, 2015). © 2015 Nessa Carey.

With a degree in immunology and a doctorate in virology, **Nessa Carey** became a senior lecturer in molecular biology at Imperial College London, where she is now a visiting professor. For just over a dozen years, she also worked in the biotech and pharmaceutical industries. In April, May, and June of 2012, *Natural History* excerpted her previous book, *The Epigenetics Revolution: How Modern Biology Is Rewriting Our Understanding of Genetics, Disease, and Inheritance* (Columbia University Press, 2012). Carey lives in Norfolk, England (www.nessacarey.co.uk).


HUG WITH CAUTION

TREES ARE VICIOUS KILLERS

As they compete for light, the crowns of several trees in a tropical forest canopy fit together like jigsaw puzzle pieces. This common pattern of branch growth, by which trees avoid direct contact and overtopping, is termed "crown shyness."

Story and Photographs by Sean O'Donnell

I am a field biologist, and I work outside whenever I can. Most of my hobbies also involve spending time outdoors: fishing, birding, and hiking. Like many other naturalists, I understand the reverence often accorded trees as wise, ancient beings, guardians of nature, solid, peaceful. Think Tolkien's Treebeard. I like trees, and occasionally I even hug them. But this warm fuzzy feeling was shaken on a recent trip to the tropical lowland rainforest of eastern Ecuador. There I began to see trees in a new light. At first I was even tempted to think of them as bloodthirsty, but I realized upon reflection that was off the mark. Trees are primarily sap-thirsty. They aren't out to get us, but they are out to get each other.

I was working with a film crew at Tiputini Biodiversity Station, and one afternoon the producer kept us on task in the forest about fifteen minutes too long as a storm squall approached. When the heavy, leaden clouds arrived overhead, the sultry stillness was broken by a sudden breeze. Snapping branches and trunks sounded like gunshots all around, followed by crashes and thuds as heavy tree parts fell to the ground. As we hiked back to the lab building I was almost happy to be distracted by a heavy downpour of rain. The next day, as I hiked alone in the quiet of late afternoon, a loud crack was followed within seconds by half of a dead tree trunk hitting the ground about fifteen feet to my left.

A primatologist working at the station related an even more harrowing close encounter with falling tree parts. A few months earlier, she and a mutual friend of ours, a fellow primatologist, were sitting on the forest floor having a lunch break. A sharp wind came up suddenly, and a large branch crashed to the ground less than a foot from our friend, very nearly reducing the forest's primate population by one.

On a previous trip to the area I had been amused to see a Huaorani Indian field assistant wearing a yellow hard hat in the forest while he collected data—amused, until I learned his father had been killed by a falling branch. On my recent trip I developed my own real dread of falling trees and branches.

After coming home from Ecuador and hiking in forests near my home in the eastern United States, I quickly lost my acute concern about tree falls. Is the threat of falling heavy tree parts really greater in tropical

At Tiputini Biodiversity Station in eastern Ecuador, a platform 130 feet up in the crown of an emergent Ceiba pentandra *tree affords a view across the rainforest canopy.*

within earshot at Tiputini? As backyard woodchoppers know, branches can be quite heavy. A tree limb a foot in diameter and six feet long weighs about 300 pounds, and a branch falling from 130 feet up will hit the ground in less than three seconds at sixty miles an hour. Timber, indeed.

One of the most amazing places at Tiputini Station—one I dashed off to whenever I could—is the canopy tower. A metal scaffolding frame and stairs lead up (and up) to a platform in the crown of a huge kapok tree (*Ceiba pentandra*) that emerges above the overall forest canopy. From the platform the view across the forest is largely unimpeded by foliage. The real irony of the nature of trees hit home when I climbed to that platform a few days after the squall. The platform tree is healthy and vigorous, yet the volume of the leaves in its crown appeared paltry relative to the size of the trunk and limbs supporting them. It was like using a high-rise apartment building as a flagpole. Why, in evolutionary terms, should a plant go to all the trouble to invest in very expensive wood, and lots of it, to hoist a few tufts of small green solar panels?

The answer is a plant version of aggressive competition. Trees are structures that resulted from fierce, albeit slow, battles: plants won this competition by pushing their leaves ever higher in an effort to beat out other plants. The contested resource was energy (sound familiar?)—in the case of plants, light energy. If plants weren't fighting over light, we'd expect the ground to be covered with broad mats of green, much as it is in prairies. Imagine a terrestrial world dominated by ground-hugging plants, the situation that likely prevailed before trees evolved. Now insert a plant that could spread its leaves on an elevated structure, rising over other plants. Above that plant would be full sun and below it would be shade, potentially rather dark shade.

It is easy to imagine the resulting evolutionary arms

forests? I believe so. First, annual primary productivity, basically the amount of carbon dioxide fixed into plant tissue per unit area, is higher in tropical lowland forests than in other forest ecosystems. There is often high standing plant biomass in tropical forests, and biomass accumulates quickly. Second, biological forces that can weaken wood, such as insect and fungal feeding, occur at higher rates. Add a lot of rain (weight) and a bit of wind (twisting forces), and you have a recipe for what ecologists euphemistically call a dynamic forest.

What happens when a branch falls from the canopy—a frequent event, to judge by the daily repeated crashes

race of increasing plant height, possibly modified by adaptations for spreading a large canopy to the sides as well—hence trees with long horizontal branches. How far can this race go? As far as needed to overtop other trees, with the upper limits set by physical restrictions on the plant's ability to transport nutrients and water between leaves and roots. Viewed from the perspective of competition among plants, a tree is a leaf's way of stealing light from rival leaves.

Falling trees' threats to humans are not directly adaptive, and trees are not malicious toward us. The danger from falling vegetation is a by-product of natural selection, the "nature red in tooth and claw" (green in leaf and branch?) type of competitive selection so favored by Victorian thinkers: survival of the fittest, where the fittest get the most energy. We have trees because one of the biggest threats to plants has been other plants, but plant violence is largely a plant-on-plant thing. Like many human conflicts, only more so, it has been going on a long time.

The tree-weapon was apparently discovered by natural selection soon after plants invaded dry land. Tall structures we could call trees were prominent in the Carboniferous period, about 300 million years ago, before the advent of the seed plant lineage that predominates now. Members of the plant group to which today's modest-size club mosses belong, the lycopsids, grew as tall as modern trees. Ferns also evolved treelike growth forms, and tree ferns even today can be impressive (but not canopy-reaching) in modern tropical forests.

But real trees are made of wood, and wood is a major evolutionary innovation of seed plants and their close relatives. Wood-producing vascular cambium, the food and water transport systems of seed plants, evolved near the origin of the seed plant lineage. The ability to grow taller, using both the strength of wood and the superior capacity of phloem (food transport) and xylem (water transport) to support very tall columns of liquid, were likely major factors in seed plants' success and their eventual rise to ecological dominance. Among other advantages, wood allowed seed plants to overtop the competition. Other plant lineages, such as the spore-bearing ferns, were left in the shade, and thereby relegated to the relatively marginal ecological importance and paltry biodiversity they now exhibit.

Wood is not always advantageous, however, and woody tissue has been lost several times in seed plant lineages as lower-growing forms evolved. These include herbs, and notably grasses and other monocots. Interestingly, tree-like growth forms later re-evolved in some monocots such as bamboos and palms. While they don't form branches, palm trunks are effectively woody, and falling palm trunks are a force to be reckoned with in tropical forests.

A mature strangler fig tree began life as an epiphyte on a branch of a tall tree and sent roots down to the ground. This one has a hollow main trunk (left) that once enclosed the host tree—now rotted away. An additional supporting trunk (right) derived from roots that descended separately from the host tree canopy.

It might seem inappropriate to use words like *fighting* to refer to competition among trees. But plants, particularly trees, operate on time scales difficult for humans to sense or even comprehend. I suspect a time-lapse observation of tree development would reveal patterns of growth akin to what we think of as behavior. I'd also bet plant growth pattens would often appear competitive, aggressive, and in some cases downright nasty when sped up. Getting and maintaining access to sufficient light energy is a very big deal to plants. Successful light harvest is probably one of the major determinants of plant fitness, and other plants are likely the most important impediment to light-foraging success. Fighting seems a fitting

Sculpted by wind in a Costa Rican cloud forest, the woody trunk and branches of a canopy tree lift a relatively sparse array of leaves into the light. A heavy load of epiphytes nearly obscures the host tree's foliage on some branches.

description, even if to us impatient animals it is duller than watching paint dry.

A commonly held notion in ecology is that biological complexity promotes ecological and evolutionary diversity. Forest structure complexity—the opportunities for multiple plant canopy layers to form beneath the highest tree canopy—is often given as an example. While true in a sense, this should not be construed as tree generosity. The plants reaching the top layer pass down precious little energy. Light levels in tropical forest understory are often less than 5 percent of the intensity striking the canopy above, suggesting that all the diversity below the tree canopy is making the best of a very bad deal.

As often happens in biology, trees' hard-fought success is exploited by cheaters. Two interesting classes of tree robbers are immediately obvious to visitors in tropical forests. The first are epiphytes: non-woody plants that "borrow" the structural support of trees. These hangers-on manage to have their seeds dispersed into the canopy and deposited on branches, where the epiphytes grow in abundant sun without investing in wood. Their presence is not trivial to their hosts. Strangler figs are a compelling example. They begin life as epiphytes on some tree, dangling roots that eventually reach the soil. The strangler then quickly grows to envelop and overtop its host, cutting off the host's vascular tissue. The host tree dies and rots, leaving a hollow fig trunk to indicate its passing. In some forests the epiphyte load is so dense as to make recognizing the leaves of the host tree difficult, and soggy mats of epiphytes add substantially to the weight of tree branches—and the risk of their breaking off. This of course compounds the threat to earthbound critters. Some tropical trees have adaptations apparently directed against epiphyte accumulation, such as smooth or shedding bark.

The second class of tree-cheaters includes vines and creepers that germinate in soil and climb tree trunks, often reaching the canopy, where they flower and fruit in full sun. In tropical forests some massive woody vines, called lianas, can live for centuries and eventually rival trees in size. They can be hundreds of yards long and span several tree crowns.

Tree structure is not the only plant weapon; plants have other ways of carrying out their quiet yet insidious battles. Some plants engage in chemical warfare, called allelopathy by ecologists. Allelopathic chemicals released by plants can inhibit seed germination or growth in potential competitors. Among temperate-zone trees, black walnut, pines, and maples have allelopathic properties. Plants thus direct defensive chemistry against animals and against each other.

There is an alternative idea about why plants were selected for increased height. If ancient herbivores—leaf-munching animals—were largely tied to the ground, selection could favor plant adaptations that moved foliage up and out of reach. Under this scenario trees are not noble, exactly, but rather reflect plants' position as hapless victims of animal depredation. However, animals are mobile and can perform such feats as climbing and flying to circumvent gravity. Growing tall is not an effective way to escape many herbivores, so my money is on plant-on-plant warfare as the prime driver of tree evolution. As a ground animal I may be a mere bystander, but perhaps it is time to add a hard hat to my tropical field-gear shopping list.

Sean O'Donnell is Associate Department Head and professor in the Department of Biodiversity, Earth & Environmental Science (BEES) at Drexel University in Philadelphia. His research interests include community ecology and biological diversity of tropical social insects, such as wasps, bees, and army ants. Among other topics, his laboratory is exploring the evolution of brain structure in social insects, including individual and caste differences in brain architecture. Previously for *Natural History* he wrote about birds that track army ants to gain a share of the spoils ("Exploiting the Infantry," July-August 2014).

MEDICAL EXAMINER BY DRUIN BURCH

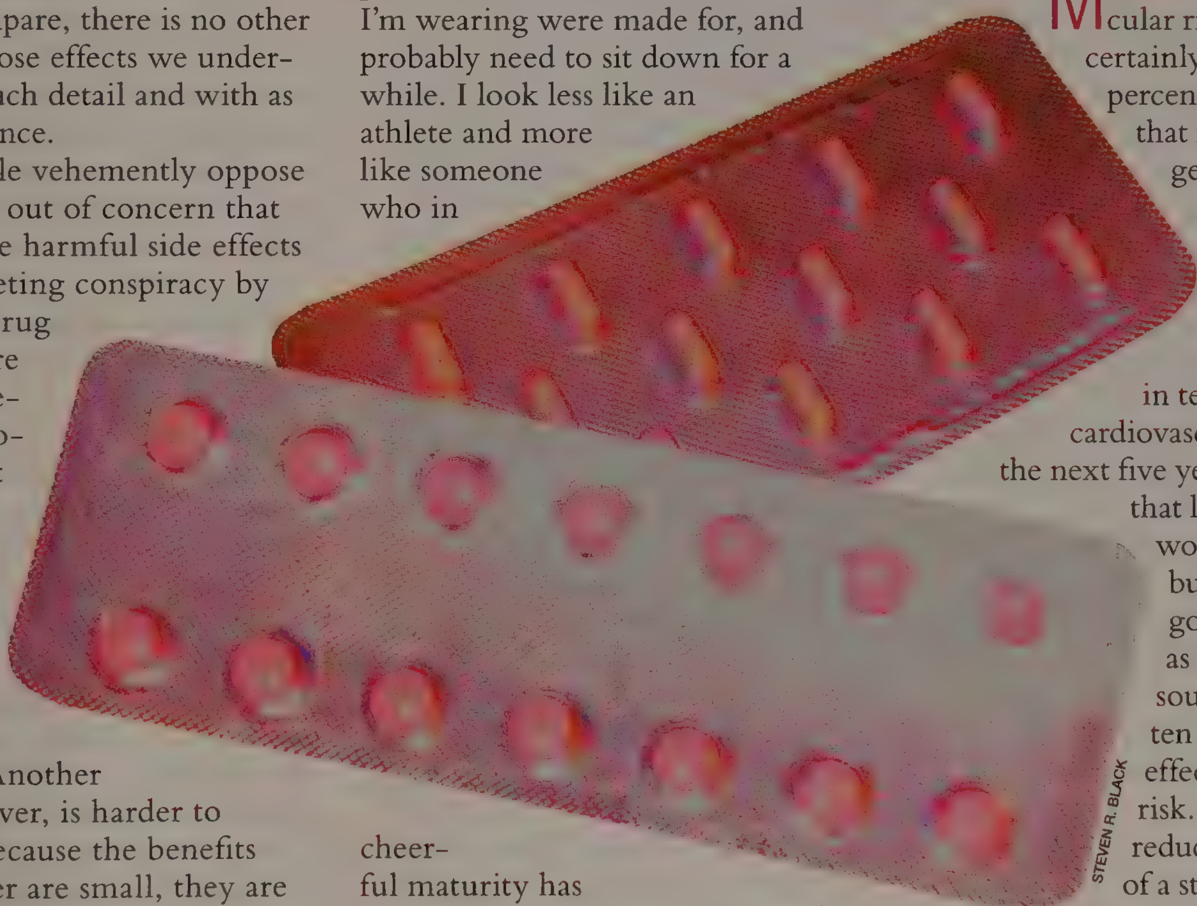
Mounting Evidence

Small things matter.

I take drugs—or I keep meaning to. Specifically, I've swallowed a few capsules of a statin and sworn to take more. I accept as my starting point that high levels of low-density lipoprotein cholesterol are associated with cardiovascular harms, and that if you lower those levels with statins, then you do yourself good. This much is supported by solid science. Although there is a lot more we wish to know about statins, particularly how different types and different doses compare, there is no other drug class whose effects we understand in as much detail and with as much confidence.

Some people vehemently oppose taking statins out of concern that they may have harmful side effects or, in a marketing conspiracy by doctors and drug companies, are being overprescribed to people who don't need them. Given proper medical oversight, neither concern should rule calm heads. Another notion, however, is harder to dispel: that because the benefits the drugs offer are small, they are no good. It's an idea that has some merit to it. Overall, though, it's badly mistaken, and understanding why is important.

Now middle-aged, I am as physically perfect as I was in my twenties: a slim never-smoker with an elite level of physical fitness and superbly low blood pressure and serum lipid levels; a youth who sleeps soundly each night for as long as my body needs, eats a nutritious diet aimed at supporting my athletic prowess, and imbibes alcohol at precisely the amount observational data suggest best improves overall mortality. But somehow, as I stroll down a corridor with a spring in my step and smug superiority shining from every pore, I spot my reflection. Strangely, it looks depressingly clear that I'm well into my forties, weigh a couple of stone more than the clothes I'm wearing were made for, and probably need to sit down for a while. I look less like an athlete and more like someone who in



STEVEN R. BLACK

cheerful maturity has developed a fondness for steak Béarnaise and Burgundy. With small children and a busy job, life is happier and more marvelous than it was in my twenties, but youth is beginning to abandon me for others. Even my parents have let me down. Year by year they get older, hardly considering what their own reckless aging implies about their son.

At any rate, I can no longer ignore the piling on of years. When the world celebrated my last birthday, I remembered my family history of heart disease. I opened a bottle of Burgundy (a rather good Clos de la Roche, since you ask) and enjoyed a rich meal of joyfulness and truffle-infused expense. Then I cracked open a pack of statins my mother had forgotten on a previous visit.

My overall cardiovascular risk is low. It's certainly under the 10 percent five-year risk that is now suggested as a cutoff for prescribing statins. (In other words, my chances are less than one in ten of having a cardiovascular event in the next five years.) Below that level, the drugs work as efficiently, but they do less good. That isn't as paradoxical as it sounds. Drugs often have consistent effects on *relative* risk. Taking a statin reduces one's chance of a stroke or a heart attack by about a fifth.

That's as true for me as for an obese eighty-year-old with severe coronary disease, a bad smoking habit, and every other risk factor going. It's also just as true for the svelte and sporty twentysomething I once was. For each of us, statins drop relative risk by pretty much the same amount.

Absolute risk is a different issue. The

chance of a young, fit athlete having a stroke or a heart attack is minuscule, so dropping it by a fifth offers little. For the unhealthy eighty-year-old, reducing risk by a fifth is a big deal. The combined data from twenty-seven trials and 170,000 patients is what makes me so sure that taking a statin will drop my chance of a stroke or a heart attack over the next five years by a fifth. Given my low absolute risk, my therapeutic drug habit might give me an extra edge of about one in fifty in avoiding cardiovascular mischief. To put it another way, after years of taking a statin there will be an overwhelming chance that I'll be as healthy as if I'd never bothered.

Given my state of health—genuinely good, despite my years—I'm not willing to give up very much in terms of lifestyle in order to gain so small a benefit. But taking statins costs me practically nothing. I reckon they're worth the deal. The chances are I won't profit, but the same is true of my life insurance policy, and it costs me rather more. My intention to start a statin at such a low level of overall risk is eccentric, exceeds the guidelines, and may well be a consequence of the paranoia that comes from spending my own medical career tending to the unfortunate. But it's a decision that is at least based on a decent understanding of the pros and cons and so, being one that suits my preferences, it is in that sense correct.

Drugs to lower my blood pressure are subject to the same calculations, as are other drugs I will end up taking as the years go by—assuming, as I like to, that my life will not end prematurely in some violent but famously brave and noble death. What's remarkable, if you survey the common interventions we use to retain and regain health, is the similarity of their degree of benefit. So much of the best of modern medicine confers a relative risk reduction of roughly the same amount—20 or 30 percent, about a fifth to almost a third. Why should that be?

Much of the best of modern medicine confers a relative risk reduction of roughly the same amount—20 or 30 percent.

As the middle of the twentieth century wore on, it became apparent that heart attacks were a growing problem. Some attempted to figure out why and prevent them, others to develop treatments to be given when they happened. It was understood that blood clots within coronary arteries were to blame, and that these came on a background of atherosclerotic plaques in blood vessels. Such plaques began to be noticeable at autopsy in remarkably young people, in those still in adolescence or their early twenties who had been cut down by war or car crashes,

In 1988 a landmark trial was carried out that tested two new treatments, despite the fact that previously, their benefits had not been reliably indicated either on the basis of clinical experience or in randomized trials. One of the drugs was aspirin, which was known to thin the blood, but only to a very small degree. It was understood to be too mild a drug to have any useful power in such a serious situation as a clogged coronary. The other treatment was thrombolysis—the delivery of a "clot-busting" drug. It was thought unfeasible for the opposite reason: it was too dangerous, too extreme. Its potential benefits were great but so were its spectacular harms: patients could literally (and dramatically) drop dead from the catastrophic bleeding it caused.

The 1988 study, however, showed that each of the two drugs *did* help when given to people suffering heart attacks. The study worked (demonstrated truth where previous tests had given a false negative) because of epistemological superiority, because it was a higher-quality examination of reality, more robust in the face of human variation and sampling errors. For all the mildness of aspirin's benefits, this study showed, its harms were also mild. And while the clot-busting drugs could cause massive and immediate problems, they could offer massive and immediate benefits, and they did so at a slightly higher rate. Altogether, when you looked at the chance of helping versus the chance of making things worse, the drugs worked out to be remarkably similar. Each dropped a heart-attack victim's relative risk of death by about a fifth. (That may sound like a lot, but actually only a very small proportion of patients suffering a heart attack die from it. Reducing relative risk of death by a fifth confers a roughly 2 percent improvement in absolute survival in the whole pool of heart-attack victims.)

Moreover, the study didn't just compare each of two treatments to a placebo. It also compared each by itself to administering the two together. The benefits of each treatment were minor, but the benefits were additive.

We tend to think of successful medicines as miracle cures and wonder drugs. It's a treacherously misleading habit. It gets in the way of accepting that medical interventions are a gamble, a balance of harms and benefits, and that even at best the two cancel each other out to a large extent. There are no absolute magic bullets: any drug without side effects is likely not a drug at all. The greater the therapeutic potential of an intervention, the more powerful are likely to be its hazards. Amid this overlapping complexity lies the explanation for why so many ef-

fective treatments are, consistently, only mildly effective.

When we fail to accept the mild benefits of most medical interventions, we miss out on seeing the reality of the world, and we make errors. As doctors and patients, when we give in to the urge to exaggerate and simplify—to see drugs as either miraculous or toxic—we often make bad choices. Similarly, many dietary or lifestyle choices are neither unreservedly evil nor good, and to be properly understood, need to be evaluated quantitatively.

Over recent years, some of the tide of noninfectious disease has begun to recede. Across the developed world, what seemed an unstoppable rise in heart attacks and strokes has begun to soften or even withdraw. For the past decade, the number of people in my homeland of Britain suffering a heart attack has dropped by 5 percent a year. Of those who do get heart attacks, the chance of dying has gone down by 9 percent annually over the same period. In the United States, trends have been similar; deaths due to stroke and heart attack are declining on a year-by-year basis.

Not all these improvements are due to drugs and medical interventions. Lipid levels in American blood have improved over the past decade, even in those not taking statins, and all despite the fact that Americans have come to eat more and weigh more over the same period. This is mysterious. But some of the improvements *are* due to drugs and medical interventions. Each pill and procedure generally, and on average, does only a small amount of absolute good. The preventive benefits of statins and of aspirin, the emergency treatments for coronary clots, the beta blockers and ACE inhibitors and other drugs that are prescribed after a cardiovascular event—each of these is far from dramatic. But they add up, and when enough of them do so, our lives become much more likely to ripen and mature with all the health we could wish for.

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A laxative marketed as something of a cure-all in the nineteenth century, Beecham's Pills continued to be manufactured until the last decade of the twentieth century, ending as The Beecham Group merged into SmithKline Beecham and later GlaxoSmithKline.

Most medical breakthroughs are modest. Be suspicious of anything that seems much better than that, particularly if it's new. These modest breakthroughs, though, often do not replace what has come before. They add to it and one day will be added to in turn. Enough small steps put together go a long way, hence the increasing number of pills we can all expect to swallow in our lives. Which is why, eternally young and athletic as I am, I take my statin. Or at least, my memory not being what it was, I keep meaning to.

DRUIN BURCH, an attending physician at the John Radcliffe Hospital in Oxford, teaches physiology, medicine, and human evolution at the University of Oxford. His most recent book is Taking the Medicine: A Short History of Medicine's Beautiful Idea and Our Difficulty Swallowing It *(Chatto and Windus, 2009).*

Resetting the Clock

After hibernation, arctic ground squirrels may need the light of day to reactivate body rhythms.

By Cory T. Williams and C. Loren Buck

As the farthest-north hibernating small mammals in North America, arctic ground squirrels (*Urocitellus parryii*) are exposed to profound seasonal changes in light and ambient temperature. Their annual cycle includes a short summer season of three to five months. During that time individuals are active aboveground and maintain a favorably warm, or "euthermic," body temperature of between 96 and 104 degrees Fahrenheit. Animals spend the remainder of the year sequestered in frozen burrow systems, during which their body temperatures fluctuate, in what is known as "heterothermy." For long bouts (two to three weeks) they are in a continuous state of torpor, reducing their metabolic rate and maintaining a body temperature below that of an ice cube. Their torpor is interrupted by brief, ten- to twenty-hour intervals during which their body temperature is elevated to a euthermic level.

For two to three weeks before first emerging to the surface from their burrows, males terminate heterothermy (the lowering and raising of their body temperature), remain euthermic, and start feeding on food they have stored. During this time, they regain their body condition and undergo testicular growth and maturation. Females, which do not appear to keep a stash of food, continue to sleep in, so to speak. They typically don't turn up their body thermostat until about four days before they emerge from their burrows and resume daily aboveground activity.

In their high-latitude habitats, arctic ground squirrels experience conditions that are far more severe in winter compared with those experienced by temperate or alpine-dwelling hibernators. Temperatures within their burrows average 16 degrees during the winter, and fall as low as –10 degrees. Furthermore, light conditions in the mid-Arctic, where these animals live, are not like other places. The midnight Sun shines at the height of summer, while in the depths of winter the Sun stays below the horizon for months at a time.

We were interested in understanding the role that circadian clocks play in this unique environment. An organism's circadian clock is the biochemical system that permits coordination of such daily physiological and metabolic processes as sleeping and eating with changes in the hours of daylight. What role, if any, do circadian clocks play in hibernation? And does an organism go "off the clock" when there are long intervals of constant light or constant darkness? How to tease apart this information from small animals in the wild, which may be burrowed underground or scurrying over the landscape, presented a challenge.

In mammals, the circadian master clock is in the suprachiasmatic nuclei of the hypothalamus in the brain; it oscillates on a twenty-four-hour cycle, keeping very accurate time when it receives daily updates on changes in hours of daylight. It transmits its rhythmic information to oscillators in other brain regions and to peripheral organs, in fact to all organs, by means of a variety of outputs, including body temperature rhythms.

The function of such clocks when environments are effectively constant is debated. In Svalbard reindeer (*Rangifer tarandus platyrhynchus*) and ptarmigan (*Lagopus mutus hyperboreus*)—species indigenous to the High Arctic—animals show short alternating bouts of activity and feeding, and circadian rhythms are absent during seasonal intervals of constant light or constant dark. The team that reported that finding in 2005, led by Bob E. H. van Oort of Norway's Center for International Climate and Environmental Research–Oslo (CICERO), proposed that pattern was common to all polar vertebrates.

Other researchers, however, have found evidence that daily rhythms of activity and physiology are maintained throughout the Arctic summer in a number of invertebrates, and in a variety of vertebrates, including fish, migratory birds, and some mammals. Similarly, we have found that arctic ground squirrels exhibit persistent circadian rhythms of activity and body temperature during summer intervals of constant sun at mid-Arctic latitudes.

The question regarding the status

UWE ANDERS

of circadian clocks during hibernation has also perplexed scientists. Earlier research on captive golden-mantled ground squirrels (*Callospermophilus lateralis*) from western North America revealed they have persistent circadian body temperature rhythms during steady-state torpor, though these rhythms were very low amplitude and may have been driven by ambient temperature changes in the environmental chambers in which they were housed. The question is, would we also see evidence for a functional circadian clock when measuring body temperature in free-living arctic ground squirrels?

We studied arctic ground squirrels near the University of Alaska Fairbanks Toolik Field Station on the North Slope of Alaska. In the spring of 2010, we implanted nine adult male ground squirrels with abdominal loggers programmed to record body temperature at thirty-four-minute intervals for up to twenty-four months; we also implanted one juvenile squirrel on August 9 with a smaller abdominal logger programmed to record core body temperature every three and a half hours for up to twenty-four months. In September 2010, each squirrel was recaptured, anesthetized, and outfitted with a temperature and light logger affixed to a neck collar made from zip ties with shrink tubing used to prevent abrasion. The light loggers enabled us to record when the squirrels moved in and out of their burrows. We thus could follow their daily aboveground activity patterns and also look for the connection between their exposure to light and the setting and resetting of circadian rhythms. Such very lightweight light meters were originally developed to record the times of dawn and dusk experienced by migrating birds, as a means to determine the latitudes of their changing locations.

In the spring of 2011, we successfully recaptured nine of the ten squirrels (one adult was not recaptured despite extensive trapping effort). Of the recaptured squirrels, one had lost its collar, one light logger failed to record, and the implanted body temperature logger of a third squirrel failed. Altogether, we obtained complete body temperature and light exposure data from six squirrels during fall entry into hibernation and heterothermy, those alternating bouts of torpor and active temperature. For four of them we also obtained complete data during the termination of heterothermy and spring emergence (on the other two squirrels, the batteries of the light loggers failed during mid-hibernation).

In the fall, before they entered hibernation, core body temperature in free-living male ground squirrels showed robust daily rhythms, rising 2.4 to 4.8 Fahrenheit degrees during the daytime. Indeed, the animals typically had an anticipatory increase in body temperature that varied from 1.2 to 2.4 degrees even before emerging from their burrows each day and being exposed to light. Daily decreases in body temperature occurred after animals returned to their dark burrows.

Of the six adult male ground squirrels from which we recovered simultaneous body temperature and light exposure data in full, five continued to maintain daytime activity patterns after their release for three to nine days before sequestering themselves in their burrows between September 22 and September 30. These animals subsequently first entered torpor anywhere from two to thirteen days later (on average, 6.6 days later). The sixth squirrel entered his burrow on September 29 and maintained warm (euthermic) body temperature levels for twenty-two days thereafter, during which he occasionally made brief forays aboveground and was regularly exposed to low-intensity light. Despite the limited time spent aboveground, he maintained twenty-four-hour body temperature rhythms. In all six animals, daily peaks in body temperature were lower, and mean body temperature was reduced when animals remained in their burrows and had no aboveground activity.

Minimum body temperature during torpor steadily decreased from October until late December, at which point the soil froze and squirrels began maintaining body temperature that was on average a little below the freezing point of water, but warmer than the surrounding soil. During steady state torpor, body temperature was constant and arrhythmic for as long as thirteen days. Light was never detected by animal-borne light loggers during heterothermy.

Collar temperature closely tracked body temperature (within 2.2 degrees) during torpor and during the intervals of euthermic arousal, but deviated frequently from body temperature after heterothermy had ended and squirrels were euthermic,

feeding on their food caches belowground. The sensor was not directly against the squirrels' skin and was thus influenced by exposure to ambient conditions when the animals were not curled in a ball within their nests.

In the spring, after ending heterothermy, the four male arctic ground squirrels for which we had complete data remained belowground for twenty-two to twenty-six days before commencing daily activity on the surface, as revealed by resumption of their regular exposure to light. In none of them did we detect significant circadian rhythms during the first ten belowground days of euthermy, suggesting that the generation of circadian body temperature rhythms had ceased at some point during heterothermy.

In general, twenty-four-hour rhythms were restored once animals resumed aboveground activity and were directly exposed to the external solar cycles. But three of four squirrels were exposed to very low-amplitude light four to twenty-three days before they initiated daily aboveground activity, and in one of these we did find that a body temperature rhythm recommenced before resumption of aboveground activity. In that case the period of the rhythm was shorter (about twenty-two hours) than a circadian rhythm that is entrained to a light-dark cycle.

Although we lack data on snow cover during this time frame, snow might account for those low-amplitude light exposures. Snow cover at the study site is intermittent and patchy during the winter months, and squirrels may have been exposed to light coming through the snow pack and into their burrow entrances. Indeed, even below ten inches of snow, light could have filtered into burrow entrances.

If the low body temperature associated with torpor in an arctic ground squirrel prevents RNA transcription and translation within the suprachiasmatic nuclei, then we anticipate the animal's master clock would stop and restart multiple times during hibernation. It would stop during torpor and restart during the arousal episodes, through some fourteen to sixteen cycles over the hibernation season, depending on the animal's sex and age. Such start-stop cycles might lead to desynchrony of individual oscillators within the master clock, thus requiring an external trigger to reset a circadian rhythm.

We cannot discount the possibility, however, that oscillators within the suprachiasmatic nuclei are synchronized and rhythmic throughout hibernation. It could be that the output pathways responsible for the generation of body temperature rhythms are inhibited for some time following the completion of heterothermy.

Likewise, our results are not inconsistent with a hypothesis recently put forward by André Malan at the Institute of Cellular and Integrative Neurosciences, CNRS (National Center for Scientific Research) and the University of Strasbourg, France. He proposes that torpor-arousal cycles are controlled by a circadian clock located in a region other than the suprachiasmatic nuclei, a clock not involved in the generation of body temperature rhythms.

CORY T. WILLIAMS is a postdoctoral research fellow in the Department of Biological Sciences, University of Alaska, Anchorage. Among his interests are the mechanisms that allow vertebrates to anticipate and respond to variation in resource availability. C. LOREN BUCK, a professor in the Department of Biological Sciences, University of Alaska, Anchorage, is an environmental physiologist who studies the adaptations of animals to extreme and variable environments.


UVE ANDERS

SKYLOG BY JOE RAO

Illusions

In May the seven-star pattern Americans know as the Big Dipper hangs high in the north as darkness falls. In the United Kingdom this asterism (as such prominent patterns are called) is better known as the Plough. A once widespread British tradition was that the stars formed a wain, or farm wagon—either Arthur's Wain (for King Arthur) or Charles's Wain (for Charlemagne). In the seventh century BC, the poet Homer described it as a bear. Interestingly, many indigenous American peoples also knew these stars as a bear. Is that sheer coincidence, or did their ancestors bring the name with them when they crossed from Asia to North America thousands of years ago?

South of the Tropic of Capricorn (23.5 degrees south latitude), however, the Big Dipper will be visible with difficulty, if at all. When I journeyed to Easter Island in 1986 to view Halley's Comet, I found the asterism a most arresting sight, lying upside down just above the northern horizon. There it seemed enlarged, thanks to the "Moon-illusion" effect. I'm sure that everyone reading these words has experienced the Moon illusion at one time or another. When it's rising or setting, the Moon appears abnormally large; when it's higher up in the firmament it looks noticeably smaller. Using the Big Dipper, you can observe another type of Moon illusion. Look at Dubhe and Merak, the so-called "Pointer" stars, the two at the front end of the Dipper's bowl—the two that line up with the North Star. Try to imagine eleven full Moons lined up in the space between them. Maybe, you'll think, one could squeeze four or five in, but *eleven*? And yet, in our sky, the Moon measures one-half degree across, while the Pointers are separated by five and a half degrees. So yes (as Goldilocks might say), eleven would fit "just right!"

COURTESY OF ZEISS

The Zeiss Skymaster ZKP 4 is the most advanced small-dome planetarium projector.

Bright things in the sky seem to look bigger than they really are. Artists know this, consciously or not, and tend to exaggerate the Moon's size in their paintings.

Interestingly, when the first Zeiss planetarium projectors were built in the 1920s, both the Sun and Moon were designed to subtend exactly one-half degree when projected on the hemispherical screen, commonly called a dome. But subjectively they appeared much too small compared with the actual Sun and Moon. So Zeiss technicians ended up doubling their size to make them appear more realistic, a practice that continues to this day.

JOE RAO is a broadcast meteorologist and an associate and lecturer at the Hayden Planetarium in New York City (www.haydenplanetarium.org).

MAY NIGHTS OUT

1 Mercury has leaped into the evening sky. About 9 P.M. local daylight time, look low to the west-northwest horizon. This innermost planet is 10 degrees to the right and slightly lower than Aldebaran, the brightest star in Taurus, the Bull. As twilight deepens, take a look at Mercury with binoculars. Just 2 degrees to its right you may be able to spot the Pleiades. On the 7th, Mercury reaches its greatest elongation (angular separation from the Sun), but it is much brighter now and almost as high as it will be then.

Also in the western sky is Venus, which reaches its peak as Evening Star in May. How soon after sunset—or even before—can you pick it out in the deepening blue? Telescopes reveal Venus swelling in diameter somewhat during the month while waning in its gibbous phase. For a few days centered on the 23rd, Venus sets about as late into the evening as it can get.

3 The Moon is full at 11:42 P.M. eastern daylight time (EDT).

5 Soon after 10 P.M. local daylight time, look for the newly risen Moon in the east-southeast and, about 6 degrees to its upper right, Saturn shining with a steady yellowish-white hue.

7 Mercury arrives at its greatest eastern elongation, 21 degrees.

9 Venus passes less than 2 degrees from the big star cluster M35, visible through binoculars at the feet of Gemini, the Twins.

11 The Moon wanes to last quarter at 6:36 A.M. EDT.

18 The Moon is new at 12:13 A.M. EDT.

21 Although they are separated by 8 degrees, Venus and the crescent Moon make for an eye-catching scene in the west-northwestern sky, with Venus to the upper right of the Moon.

22 Saturn, now in the constellation Libra, the Scales, reaches opposition: that is, the planet is opposite the Sun in our sky. It is unusually bright because its rings are tilted 24 degrees toward us (the rings will reach their maximum tilt, 27 degrees, in 2017). The red star Antares, the brightest star in Scorpius, the Scorpion, is 10 degrees to the southeast.

23 Standing high above the wide crescent Moon, and well away to the upper left of Venus, is Jupiter. The planet comes into sight as soon as the sky starts getting dark and remains beautifully placed for telescopic viewing at nightfall.

25 The Moon waxes to first quarter at 1:19 P.M. EDT.

EXPLORING SCIENCE AND NATURE

Around the Country

The Science and Significance of the Dead Sea Scrolls

The California Science Center has now opened *Dead Sea Scrolls: The Exhibition,* the largest of its kind ever mounted outside of Israel, featuring over 600 ancient artifacts. Over half of the scrolls on display—manuscripts composed, copied, and hidden in caves 2,000 years ago—have never before been seen in the United States, and some have never been exhibited since their discovery in 1947. Of special interest will be sections from ten of the Dead Sea Scrolls, including parts of the oldest discovered copies of the Hebrew Bible, also known as the Old Testament. The fragmentary scrolls in the exhibition contain passages from Genesis, Isaiah, Psalms, and even an ancient marriage contract dated to the 1st century AD. Visitors will experience the Dead Sea Scrolls within the rich historical and cultural context of ancient Israel. Through multimedia exhibits, guests will explore the science and technology used to date, assemble, and preserve these ancient manuscripts for future generations. Additional highlights include a three-ton stone from Jerusalem's Western Wall, limestone capitals from the First Temple period (1000-586 BC), ossuaries (ancient bone boxes) from the early Roman period, and a signature preserved for millennia on the unique Archer Seal. Among the artifacts from the Bronze Age to the Byzantine period in Israel are examples of delicate jewelry, pottery shards bearing royal seals, weapons including sling-stones and arrowheads, and many objects excavated from active archaeological sites in Israel.

MATTHEW PEYTON

Two small pottery lamp handles with symbol of the cross, a small plaster menorah, and a large marble slab with menorah are just some of the artifacts on display in the "Dead Sea Scrolls" exhibition.

Exposition Park
700 Exposition Boulevard, Los Angeles
323-SCIENCE (323-724-3623) • www.californiasciencecenter.org
Exhibition runs through September 7

ARIZONA
Phoenix

ARIZONA SCIENCE CENTER
Ongoing: **"Solarville."** Step off the elevator and board the Solar Light Rail to begin your journey. Once in Solarville, you will stroll through scientific labs that study the sun and learn about sustainable green energy—including alternative fuels such as algae and poop. Lend a hand in developing wind engine turbines and inventing new garbage waste systems. Also learn about cutting-edge technologies being implemented to address sustainable energy in businesses and cities around the world.
600 East Washington Street
602-716-2000
www.azscience.org

CALIFORNIA
Los Angeles

NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY
Through June: **"*Gone With the Wind*—Scarlett O'Hara's Dress."** The newly conserved green-and-white dress worn by Scarlett O'Hara (actress Vivien Leigh) to the barbeque at the Twelve Oaks Plantation in the iconic film *Gone With the Wind* is on public view for the first time. To coincide with the 75th anniversary of the film's release, the dress is featured for six months in the permanent exhibition **"Becoming Los Angeles,"** the story of the city's evolution over the past 500 years.
Exposition Park
900 Exposition Boulevard
213-763-DINO
www.nhm.org

San Diego

SAN DIEGO NATURAL HISTORY MUSEUM
On view now: **"Skulls."** View nearly 200 of the weirdest, wildest, and all-around most fascinating skulls. Rarely on display, the skulls featured are research specimens of animals from around the world—mammals, birds, reptiles, and amphibians, ranging from the big and spectacular (a rhinoceros, a bighorn sheep, a giraffe) to the miniature (California's own tiny Western black-headed snake).
Balboa Park
1788 El Prado
619-232-3821
www.sdnhm.org


SAN DIEGO NATURAL HISTORY MUSEUM

A case of specimens in the "Skulls" exhibition, now on view at the San Diego Natural History Museum.

COLORADO
Denver
DENVER MUSEUM OF NATURE AND SCIENCE
Through September 7: **"Mythic Creatures: Dragons, Unicorns, and Mermaids."** For thousands of years, humans have brought mythic creatures to life in stories, songs, and works of art. Explore these wondrous creatures and uncover the truths behind the myths. Encounter large models of mythic and real creatures, see real artifacts and fossils, and create your own creature.
2001 Colorado Boulevard
303-370-6000
www.dmns.org

CONNECTICUT
New Haven
PEABODY MUSEUM OF NATURAL HISTORY
Ongoing: **"Fossil Fragments: The Riddle of Human Origins."** This permanent exhibition tells the story of the continuing scientific search for our ancestry, and of what we know of different kinds of hominids that once lived in the distant past.
Yale University
170 Whitney Avenue
203-432-5050
www.peabody.yale.edu

DELAWARE
Wilmington
DELAWARE MUSEUM OF NATURAL HISTORY
Through May 25: **"The Robot Zoo."** Three robot animals and seven hands-on activities illustrate fascinating real-life characteristics, such as how a chameleon changes colors and a fly walks on the ceiling. The larger-than-life-size animated robots include a chameleon, a platypus, and a giant house fly. Machinery in the robot animals simulates the body parts of their real-life counterparts. In the robot animals, muscles become pistons, intestines become filtering pipes, and brains become computers.
4840 Kennett Pike
302-658-9111
www.delmnh.org

FLORIDA
Gainesville
FLORIDA MUSEUM OF NATURAL HISTORY
Through May 31: **"Panama: Tropical Ecosystem."** Focusing on Panama's biodiversity and the importance of nature to Panamanian culture, this exhibition presents photographs, stereographs, plant illustrations, and books highlighting the rich diversity of flora and fauna in the land between North and South America.
University of Florida,
Cultural Plaza
SW 34th Street and Hull Road
352-846-2000
www.flmnh.ufl.edu

GEORGIA
Atlanta
FERNBANK MUSEUM OF NATURAL HISTORY
Opening June 6: **"Brain: the Inside Story."** Filled with hands-on activities, this exhibition is a high-energy exploration of topics as diverse as the neurochemistry of love, how memory is formed, neuroplasticity and the health of the brain, and the intriguing soon-to-be-reality of the futuristic brain.
767 Clifton Road NE
404-929-6300
www.fernbankmuseum.org

HAWAII
Honolulu
BISHOP MUSEUM
Ongoing: **"Richard T. Mamiya Science Adventure Center."** This 16,500-square-foot facility adds a new dimension to the museum by providing exhibits that are immersive and interactive, with a strong emphasis on fostering a better understanding of Hawaii's environment. Visitors become active participants in exploring areas of science in which Hawaii has gained international recognition for cutting-edge research—including volcanology, oceanography, and biodiversity.
1525 Bernice Street
808-847-3511
www.bishopmuseum.org

IDAHO
Idaho Falls
MUSEUM OF IDAHO
Ongoing: **"Lewis and Clark in Idaho."** Find out how the two famous explorers influenced events in Idaho, see a re-created Shoshone Village, and learn about Idaho cultural and natural history.
200 North Eastern Avenue
208-522-1400
www.museumofidaho.org

MEMBERSHIP HAS ITS REWARDS

Institutions marked with a globe icon participate in the Passport program run by the Association of Science-Technology Centers (ASTC). If you're a member of a participating museum or science center, you may receive free admission at nearly 350 other museums and science centers around the world.

See www.astc.org/passport for more information.

ILLINOIS

Chicago

THE FIELD MUSEUM

Through October 4: **"Vikings."** The popular image of the Vikings—fierce raiders with horned helmets—is being challenged by a more complex picture. *Vikings,* the exhibition, reveals new insights brought to light through archaeological discoveries. See into the lives of these legendary people through more than 500 artifacts, many never before seen outside of Scandinavia.

1400 South Lake Shore Drive
312-922-9410
www.fieldmuseum.org

MASSACHUSETTS

Cambridge

HARVARD MUSEUM OF NATURAL HISTORY

New Permanent Exhibition: **"Birds of the World Gallery."** This bright, newly remodeled gallery captures the staggering diversity of birds with hundreds of stunning specimens, representing over 200 different bird families. New exhibition displays reveal the very latest in surprising scientific discoveries about the evolution of these modern dinosaurs.

26 Oxford Street
617-495-3045
www.hmnh.harvard.edu

MINNESOTA

Minneapolis

BELL MUSEUM OF NATURAL HISTORY

Ongoing: **"Diorama Halls."** The renowned Diorama Halls of the Bell Museum have been educating visitors for decades. From caribou to bald eagles and badgers to wolves—get a "slice of life" view of these incredible animals in their natural habitats.

University of Minnesota
10 Church Street, SE
612-624-7083
www.bellmuseum.umn.edu

The cultural history of dragons is closely examined in the exhibition "Mythic Creatures: Dragons, Unicorns, and Mermaids," now on view at the Denver Museum of Nature and Science. [*see listing on page 41*]

MISSOURI

Saint Louis

SAINT LOUIS SCIENCE CENTER

Ongoing: **"Energizer Machine."** Experience the wonder of simple machines working together in this amazing kinetic sculpture. Colored balls travel along a quarter mile of track, going through loops, flying into nets, and more! Try using your energy to lift balls into the machine at the Energizer Wheel located in the Emerson Lobby.

5050 Oakland Avenue
800-456-SLSC
www.slsc.org

NEW MEXICO

Albuquerque

NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE *Ongoing:* **"FossilWorks."** This exhibition features the process of extracting dinosaur fossils from the rock matrix that has encased them for millions of years. **FossilWorks** is a public display area in which volunteer preparators—who have completed a special training course—demonstrate the painstaking process of paleontological preparation.

1801 Mountain Road NW
505-841-2800
www.nmnaturalhistory.org

NEW YORK

New York

AMERICAN MUSEUM OF NATURAL HISTORY

Through August 9: **"Nature's Fury: The Science of Natural Disasters."** Earthquakes. Volcanoes. Tornadoes. Hurricanes. Find out how nature's forces shape our dynamic planet—and how scientists are helping to make better predictions and prepare for future events.

Central Park West at 79th Street
212-769-5100
www.amnh.org

Tupper Lake

THE WILD CENTER, NATURAL HISTORY MUSEUM OF THE ADIRONDACKS

Ongoing: **"Living River Trail."** Follow a river's course from the mountains down to the marshlands, and along the way discover bog, forest, and stream ecosystems. You'll also find the plants and animals that live in these environments, including live river otters and rare brook trout species.

45 Museum Drive
518-359-7800
www.wildcenter.org

NORTH CAROLINA

Durham

MUSEUM OF LIFE AND SCIENCE

Ongoing: **"Flip It, Fold It, Figure It Out!—Playing with Math."** This exhibition uses everyday activities to reveal the hidden math principles we all use on a regular basis. Make a quilt, slice a pizza, create rhythmic tunes, estimate which juice container holds the most liquid, and more.

433 West Murray Avenue
919-220-5429
www.ncmls.org

Raleigh

NORTH CAROLINA MUSEUM OF NATURAL SCIENCES

Through May 31: **"Photo Competition Winners."** The North Carolina Wildlife Resources Commission

has announced the winners of its 10th annual *Wildlife in North Carolina* magazine photo competition. The grand prize winning photo, along with 30 other winning images in 10 different categories, are on display.
11 West Jones Street
919-707-9800
www.naturalsciences.org

OREGON
Eugene

MUSEUM OF NATURAL AND CULTURAL HISTORY
Ongoing: **"Highlights of the Jensen Arctic Collection."** Journey into the unique cultures and ecosystems of the Arctic. Adopted from Western Oregon University, the Jensen Collection represents one of the largest assemblages of Arctic material in the lower forty-eight states, and is a valuable record of life in a rapidly changing region.
1680 East 15th Avenue
541-346-3024
natural-history.uoregon.edu

PENNSYLVANIA
Philadelphia

THE ACADEMY OF NATURAL SCIENCES OF DREXEL UNIVERSITY
Opening May 16: **"Animal Grossology."** This hands-on 3-D exhibition oozes with disgusting science and provides a slightly off-kilter view of the animal kingdom. Learn why cows chew cud and why snail and slug slime might provide scientists with insight into treating cystic fibrosis. From poop to pellets and scales to hairballs, check out all the things you aren't allowed to discuss at the dinner table!
1900 Benjamin Franklin Parkway
215-299-1000
www.ansp.org

TEXAS
Houston

HOUSTON MUSEUM OF NATURAL SCIENCE
Through September 7: **"Samurai: The Way of the Warrior."** The term *samurai*, roughly translated as "those who serve," refers to armed supporters of wealthy landowners going back to the late 8th century AD. Over time, the samurai gained power and became warrior-administrators during a period known as the Age of the Samurai. In this exhibition, there are exquisite objects related to the war-fare of these legendary warriors—full suits of armor, helmets, swords, sword-hilts, and saddles—as well as objects intended for more personal use—lacquered writing boxes, incense trays, and folding chairs.
5555 Hermann Park Drive
713-639-4629
www.hmns.org

UTAH
Salt Lake City

NATURAL HISTORY MUSEUM OF UTAH
Ongoing: **"Great Salt Lake."** The compelling narrative of the Great Salt Lake, a remnant of ancient Lake Bonneville, is brought to life through hands-on interactives, sounds, smells, and a spectacular view of the lake itself. Take a "walk around" this large terminal body of water in the midst of a vast inland desert. Get an up-close view of some of the lake's smaller inhabitants.
301 Wakara Way
801-581-6927
nhmu.utah.edu

WASHINGTON
Seattle

PACIFIC SCIENCE CENTER
Through May 25: **"Pompeii: The Exhibition."** This exhibition features over 150 precious artifacts on loan from the Naples National Archaeological Museum in Italy. These objects offer a glimpse into the opulent lifestyle and tragic end of this ancient Roman society, forgotten for centuries until its rediscovery over 250 years ago. As the floors shake and the walls rumble, relive the volcano's catastrophic eruption through an immersive CGI experience.
200 Second Avenue North
206-443-2001
www.pacsci.org

WISCONSIN
Milwaukee

MILWAUKEE PUBLIC MUSEUM
Ongoing: **"The Hebior Mammoth."** On display in the Atrium, the 14,500-year-old Hebior Mammoth skeleton, 90 percent complete, is the largest wooly mammoth ever excavated. Butchering marks on its bones help establish the early presence of humans in North America.
800 West Wells Street
414-278-2702
www.mpm.edu

Grand prize winner in the *Wildlife in North Carolina* magazine photo competition, photographer Neil Jernigan's image shows a great egret wading in a canal at Lake Mattamuskeet National Wildlife Refuge on the coastal plain. See all the winning entries on display at the North Carolina Museum of Natural Sciences in Raleigh.

THIS LAND BY ROBERT H. MOHLENBROCK

Duck Soup

Flooding an Illinois forest attracts waterfowl.

U.S. FOREST SERVICE

Turkey Bayou

The state of Illinois had not yet entered the Union when, in the early 1800s, pioneers from Kentucky, Tennessee, and the Carolinas first settled along the banks of the Mississippi River, around what is now the village of Grand Tower. The settlers found a dense bottomland hardwood forest that stretched more than twenty miles to the north and eastward up to four miles, where the bottomland ended abruptly at the foot of 200- to 300-foot-tall cliffs. This swampy woods, dominated by oaks, became known as the Oakwood Bottoms.

Since the settlers were mostly farmers, they began clearing and draining much of the forest in order to plant their crops. The floodplain soil was rich and crops flourished, but in far too many years flooding of the Mississippi River and one of its tributaries, the Big Muddy River on the east side of the bottomland, wiped out the harvest. Although several generations of families continued to farm this area, others abandoned the land and let it return to its natural forest conditions. In 1933, the United States government began to acquire the abandoned farmland and transfer it to the newly formed Shawnee National Forest.

Because the Oakwood Bottoms are on the Mississippi flyway, where migrating geese and ducks fly southward from the north, with thousands of those birds spending the winter in southern Illinois, the Forest Service decided in 1964 to create what is known as a greentree reservoir—an area of bottomland hardwood forest that is subjected to controlled, shallow flooding in the fall and winter. Several wells were drilled so that water could be pumped out to cover the area to a depth of six to eighteen inches. The flooding is carried out each year around October 1. Ditches that were dug crisscrossing the area are used to

© MICHAEL FURTMAN

Male wood ducks

Pennsylvania bittercress

BEVERLY MOHLENBROCK

drain the water around February 15.

The wetland thus created is approximately five miles long and one and a half miles wide. The flooding provides ample water for the growth of trees, and as a result, the oaks produce many more acorns, which attract ducks. Hunting for ducks and other waterfowl is permitted within seasons and bag limits that are set by the Illinois Department of Natural Resources. For other visitors, an interpretive site with two nature trails is accessible off Oakwood Bottoms Road.

While the extra water has attracted more birds, it is also conducive to the growth of a wide diversity of plants. A number of species in the greentree reservoir and surrounding Oakwood Bottoms forest are generally rare for the region. It is the only place in Illinois for parsley hawthorn, Bush's new hawthorn, finger dogshade, and palmate dogshade. It is one of only a few places in Illinois for copper iris, featherfoil, whitenymph, broad-winged caric sedge, giant caric sedge, fanwort, narrow-leaved crabapple, blue hydrolea, lake cress, and two kinds of mock bishop's-weeds. Most of these are southern species at the northernmost limit of their range in the central United States.

Another interesting phenomenon is the number of members of the carrot family living in the wetlands, which includes some of the regionally rare species mentioned above. The carrot family is well known in the United States and includes such common roadside weeds as Queen Anne's lace, wild parsnip, hedge parsley, and wild fennel. The Oakwood Bottoms boasts thirteen less common native species, more than I've seen in any similar-size wetland in the nation.

Three plant communities exist within the greentree reservoir, although they often overlap each other. Swampy woods cover about 90 percent of the area, but a mesic community occurs on slightly elevated portions. A few low depressions occur within the swampy woods where pools of water form following heavy rains and often stand throughout the year. To the east, a streambank community borders the Big Muddy River and a body of water nearby called Turkey Bayou.

©JOE LEMONNIER

VISITOR INFORMATION
Mississippi Bluffs Ranger District
Shawnee National Forest
521 North Main Street
Jonesboro, IL 62952
618-833-8576
www.fs.usda.gov/Shawnee

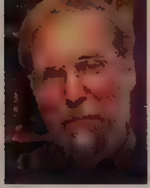
Robert H. Mohlenbrock is a distinguished professor emeritus of plant biology at Southern Illinois University Carbondale.

Swampy woods Pin oak, swamp chestnut oak, swamp white oak, cherrybark oak, green ash, and American elm are the dominant trees, with lesser numbers of water locust, bur oak, sweet gum, swamp red maple, sugarberry, swamp cottonwood, and kingnut hickory. Buttonbush is the predominant shrub, and several kinds of wild grape vines climb on the vegetation. The forest floor is characterized by wood reed, white grass, and Virginia wild rye—all grasses—and numerous sedges, along with such flowering herbs as swamp buttercup, Pennsylvania bittercress, and lizard's-tail. Plants rare in Illinois that occur in this swampy woods are parsley hawthorn, Bush's new hawthorn, copper iris, broad-winged caric sedge, giant caric sedge, narrow-leaved crabapple, and blue hydrolea. Native species in the carrot family are water parsnip, finger dogshade, tansy dogshade, two mock bishop's-weeds, whitenymph, water hemlock, bulblet water hemlock, cowbane, and cow parsnip.

Mesic woods Occupying slightly elevated areas, particularly at the northern end of the greentree reservoir, is a mesic woods where shagbark hickory, pecan, persimmon, red mulberry, and winged elm dominate above a shrub layer of spicebush. Herbs are smooth buttonweed, great blue lobelia, stingless nettle, bluestar, and blunt-leaved bedstraw. Native species in the carrot family are honewort and two kinds of wild chervil.

Depressions Following heavy rains, pools of water fill shallow depressions in the swampy forest, and these areas of standing water, ranging in size from a few square feet to nearly one acre, are home to a mixture of low-growing herbs such as lake cress, fanwort, two kinds of small-flowered buttercups, featherfoil, water smartweed, slender smartweed, mermaid-weed, blue flag, duckweeds, and water starwort.

Streamside Silver maple, box elder, eastern cottonwood, sycamore, and black willow grow here. Because of frequent inundation owing to the overflow of the river and bayou, herbaceous vegetation is limited to two kinds of touch-me-nots, clearweed, stingless nettle, various smartweeds, fowl manna grass, and little-leaved aster.



BOOKSHELF BY LAURENCE A. MARSCHALL

Cowed: ***The Hidden Impact of 93 Million Cows on America's Health, Economy, Politics, Culture, and Environment***
by Denis Hayes and Gail Boyer Hayes
W. W. Norton & Company, 2015;
400 pages, $27.95

You may get the impression from many of its chapter titles—"Don't Have a Cowburger," "Cannibal Cows," "Don't Be Cruel"—that this new book by environmentalists Denis Hayes and Gail Boyer Hayes is a spirited defense of vegetarianism. Reading on, however, you will find that they not only love cows but respect many cattlefolk, and might even consider a nice steak on special occasions. What they find objectionable is the way most dairy and beef cattle are raised nowadays—in huge milking barns and feedlots—and the overconsumption of beef by the public. Meat isn't the problem; industrial farming is.

The welfare of those cows is no trivial matter: the collective cattle of the United States weigh two and a half times what all the people do, and how this bovine population is treated has enormous impact, not on just the animals themselves, but also on both public health and environmental quality. Industrial feedlots, or CAFOs (concentrated animal feeding operations), some of which hold in excess of 100,000 cattle at a time, produce enormous amounts of animal waste. Cows spend their days in enclosures as packed as a Tokyo subway at rush hour, standing in puddles of their own droppings, which have to be flushed out daily into large sewage lagoons. And because the crowded conditions favor the transmission of diseases, feedlot cows are routinely given small doses of antibiotics in their feed, a practice that reduces—but does not eliminate—the contamination of beef and milk, can affect those who eat beef, and contributes to the spread of antibiotic resistance in bacteria. There's even mad cow disease to worry about.

Beef and milk production, the Hayeses also point out, is enormously inefficient in the use of natural resources. It's been estimated that 300 gallons of water go into the making of a single Starbuck's Frappuccino, most of it to make the cream. Forty calories of energy—in the forms of fossil fuel, solar energy stored in feed, manufacture of fertilizer and pesticides for the feed, and so on—go into producing one calorie's worth of beef protein. Vast fields are devoted to growing feed corn, because it is an easy way to fatten feedlot animals, even though grass is better for their digestion (corn "is like candy to cows"), and free-range cattle can be raised on marginal terrain rather than rich farmland.

Despite all this, the Hayeses find much to celebrate—in the growth of organic farming and sustainable methods of cattle management. Though most chapters begin with a gloomy assessment of current practice, they mostly end with visits to people who are doing it right: ranchers who encourage their free-range cattle to mimic the habits of wild grazers, worm ranchers who turn tank trucks full of cow manure into useful "vermicompost," artisan cheesemakers who have working relations with contented cows.

Cowed thus joins a growing body of literature, exemplified by Michael Pollan's *The Omnivore's Dilemma: A Natural History of Four Meals* (Penguin, 2007), that aims at informing the public about where we get the things we eat. As Ogden Nash once quipped, "It's a wise child that knows its fodder."

Hawthorn: ***The Tree That Has Nourished, Healed, and Inspired Through the Ages***
by Bill Vaughn
Yale University Press, 2015;
272 pages, $30.00

Living deep in the Pennsylvania woods a while back, I became familiar with the trees that shaded my house and provided fuel for the stove—oak, ash, tulip poplar, hemlock, and locust—but I knew nothing about hawthorns (*Crataegus douglasii*) until this book arrived in the mail. Nature writer Bill Vaughn knew little about them either, until his foot had an unfortunate encounter with a hawthorn's inch-long thorns. That was more than a decade ago, shortly after he and his wife moved to a Montana ranch, which by his own count they share with 136 of the hardy trees (or maybe it's only 2; hawthorns send up lots of trunklike shoots called suckers). The gnarled branches, menacing thorns, and dense foliage of the hawthorn sparked a bit of research, and he soon realized that it had a rich history, a tale well worth telling. His gnarly neighbors were members "of a feared, venerated species that played a quiet but significant role for thousands of years in cultures all over the world."

The result is a rambling, digressive narrative, as tangled---and sometimes as thorny—as the hawthorn itself. First and foremost, the hawthorn's densely intertwined branches have provided an ideal matrix for hedges in Europe for more than five millennia. The art of creating hedges, or hedge "laying," is well developed: there's a National Hedge Laying Society in

England that maintains lists of state-certified artisans. Or you can do it yourself, following illustrated instructions provided by Vaughn.

Hedges are living fences, but they have an importance that goes beyond just holding in livestock. The British Enclosure Act of 1845 legitimized the ongoing hedging-in of what had once been common grazing land, allowing rich landlords to seize and seal off property and furthering the concentration of wealth that accompanied the Industrial Revolution. Although designed for agriculture, hedges also have a military history: In Normandy a region of dense hedges called the *bocage* proved almost impenetrable to tanks, seriously slowing the Allied advance following D-Day.

But hedges are only one of many natural and social landscapes occupied by hawthorns. Blackfeet Indians used haws—the hawthorn fruit—as a laxative; Kwakiutl of the Northwest chewed hawthorn leaves to make a poultice for swellings; ancient Chinese brewed an alcoholic beverage from haws; known in Mexico as *tejocotes*, haws are the key ingredient in *ponche Navideño*, a traditional hot punch served in the Christmas season.

The hawthorn also connects to the tradition of the crown of thorns that Pilate's soldiers placed on Jesus to mock him: Europeans imagined it was made of hawthorn. Supposed remnants of that crown have been venerated in Europe for centuries, and today the "official" crown rests in a reliquary of crystal, silver, and gold in Paris's Notre Dame, where it is frequently paraded before the faithful.

Vaughn is clearly captivated by the hawthorn, both as a natural phenomenon and as a mythic force. He admires its grizzled appearance, its value to man and animal, and its ability to survive drought, fire, grazing animals, and the plow. Since that first encounter with its thorns, he's devoted fifteen years to exploring the genus's rich history and distilling it into a narrative. Call it a gentle madness if you will, but I recommend sharing it.

How to Clone a Mammoth: *The Science of De-Extinction*

by Beth Shapiro
Princeton University Press, 2015; 240 pages, $24.95

Current dispatches from the frontiers of what Beth Shapiro, a biologist at the University of California Santa Cruz, calls "ancient DNA" research contain both good news and bad news. The good news is that molecular biologists have developed efficient methods of extracting and mapping DNA sequences from both museum samples and naturally preserved organic material. Shapiro has used those methods to investigate remains ranging from passenger pigeons a little over a century old to bees trapped in amber millions of years ago.

The bad news, at least if you harbor hopes that Shapiro and her colleagues will soon restore mammoths to the Arctic and moas to New Zealand, is that DNA doesn't age very well, and that cloning long-dead species back into existence is almost certainly a scientific impossibility, even with the new analytic tools. Heat, water, and sunlight can denature genetic material in less than a year, rendering most tropical species unsalvageable. Mammoths, which are far better preserved in their frigid Arctic habitat, can retain short fragments of DNA much longer, perhaps several tens of thousands of years, although unbroken genes never survive. As for those millions-of-years-old bees, nothing remains of their original DNA. If you were planning on investing in brontosaurus futures, forget about it.

Nevertheless, Shapiro sees a place for de-extinction efforts aimed not at restoring exact replicas of paleo-wildlife, but at creating functional equivalents of vanished species, engineered with advanced genetics to incorporate crucial features that are now extinct. Using the fragmentary DNA of mammoths, for instance, scientists can identify stretches of genome that code for the hairy coats and oxygen-receptive hemoglobin required for survival in cold climates. These genes can be inserted into the chromosomes of African elephants, the closest living relatives of mammoths, to produce mammoth-like pachyderms that would feel at home in the tundra.

But how do you train creatures born in captivity to cope with a totally unfamiliar environment? How do you ensure a sufficient number and diversity of "new" creatures to sustain a stable population? Where do you set them free, given that changes in their original habitat may have led to extinction in the first place? Recent experience with reestablishing such living but endangered species as the California condor indicate that these problems are at least as difficult as those of genetically resurrecting totally vanished species.

What makes all this effort worthwhile, however, is its broader environmental impact. Reintroducing large herbivores to Siberia, to give one example, is a way of transforming frozen tundra to productive grassland in a relatively short time, an effect that has already been demonstrated on a limited scale by Russian ecologists. As Shapiro sees it, de-extinction isn't about geeky genetic sleight of hand or about the resurrection of legendary beasts; it's a valuable new tool for conserving and enriching the global ecosystem.

Laurence A. Marschall is a professor of physics emeritus at Gettysburg College in Pennsylvania. His most recent books, coauthored with Stephen P. Maran, are Pluto Confidential: An Insider Account of the Ongoing Battles over the Status of Pluto *and* Galileo's New Universe: The Revolution in Our Understanding of the Cosmos *(both Ben- Bella Books, 2009).*

Bathing Beauty

STORY AND PHOTOGRAPHS BY ETHAN J. TEMELES

Hummingbird: the word conjures up a vision of a sparkling jewel hovering in the air. The last thing a person expects to see is a hummingbird lying amid leaf litter on the ground. But that's exactly what I found one drizzly March day while surveying hummingbirds and the flowering plants they feed on in the cloud forest around Freshwater Lake, Dominica.

The bird—an adult male blue-headed hummingbird (*Cyanophaia bicolor*)—darted up and into the forest as I approached, but quickly returned to its previous spot on the ground when I stood still. Looking around, I noticed that the bird had chosen the only patch of sun coming through the mist of the cloud forest,

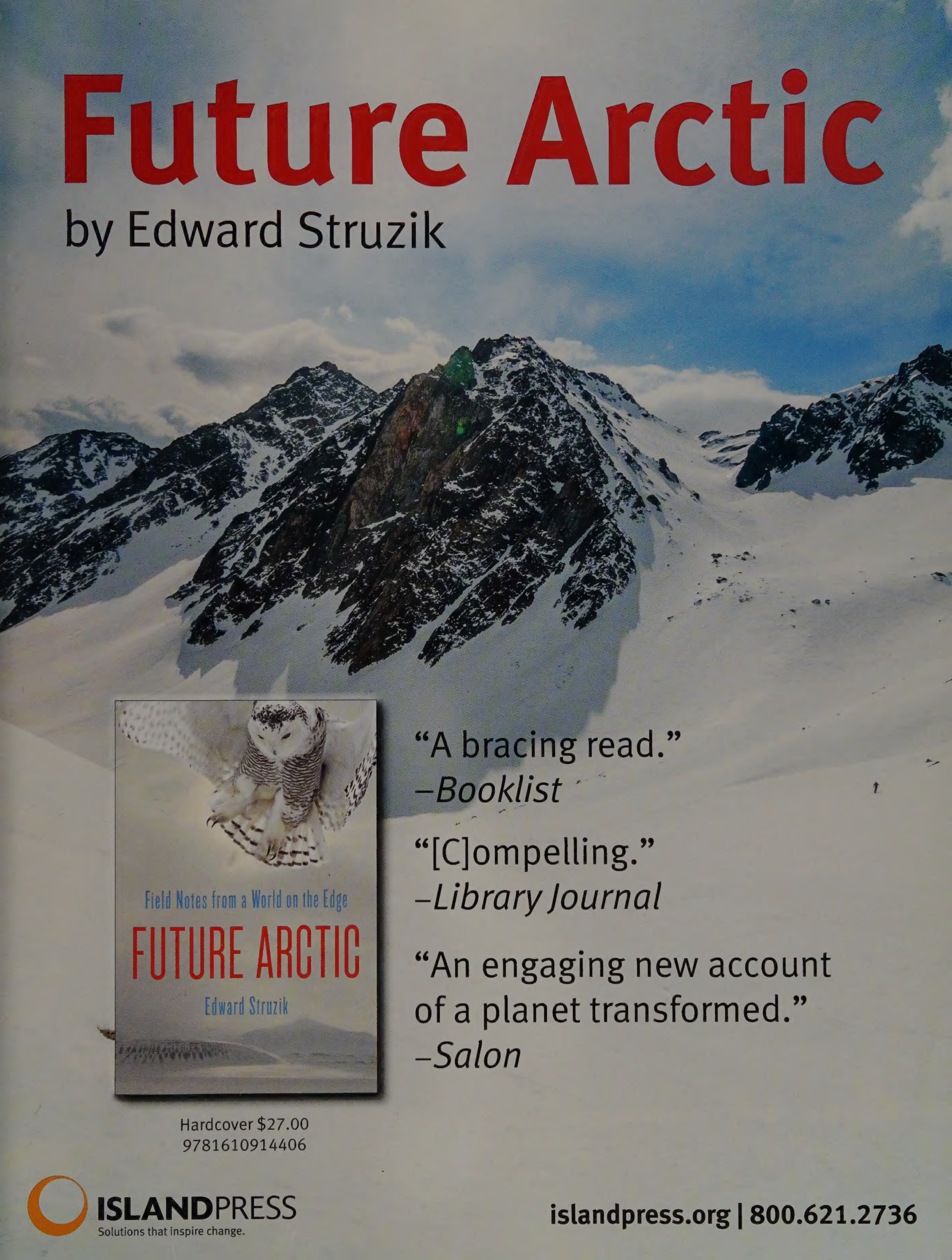
and I realized that it was sunbathing. So intent was the bird on getting warm that I had time to remove a camera from my backpack, attach a telephoto lens and a flash, and take the picture above. Below left, the bird sips nectar from a gesneriad plant, *Besleria lutea*, related to mint plants.

Hummingbirds, along with swifts, belong to the avian order Apodiformes, a Greek word meaning "without feet" in reference to their small legs, used only for perching. Although hummingbirds usually hover in the air when feeding at flowers, some species, such as the blue-headed hummingbird, will use perches when feeding.

Blue-headed hummingbirds are found only in the elfin cloud forest and upper rain forests of Dominica and Martinique, two islands in the Lesser Antillean archipelago of the Eastern Caribbean. Freshwater Lake, where I took these two photographs, is part of Morne Trois Pitons National Park, a UNESCO World Heritage Site. The park includes the most extensive pristine tropical forest in the Lesser Antilles and is part of a Conservation International Biodiversity Hotspot and Center of Plant Diversity. Other hummingbirds a visitor may observe there are the purple-throated carib (*Eulampis jugularis*) and Antillean crested hummingbird (*Orthorhyncus cristatus*). Other birds include two parrots: the imperial Amazon, threatened in Dominica, and the red-necked Amazon, now rarely observed in only a few small areas of the park.

Morne Trois Pitons National Park is at its most spectacular from March through May, when a wide variety of plant species are in flower. Then the hummingbirds, bats, and hawkmoths come out in force to dine and, in doing so, serve as polllinators.

Ethan J. Temeles is the Thomas B. Walton, Jr., Memorial Professor of Biology and Chair of the Department of Environmental Studies at Amherst College, Massachusetts, and a research associate of the Smithsonian Institution. For more information on his work on hummingbirds and their food plants, readers can view his previous articles in Natural History *and elsewhere at* www3.amherst.edu/~ejtemeles.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